GENERAL MOTORS

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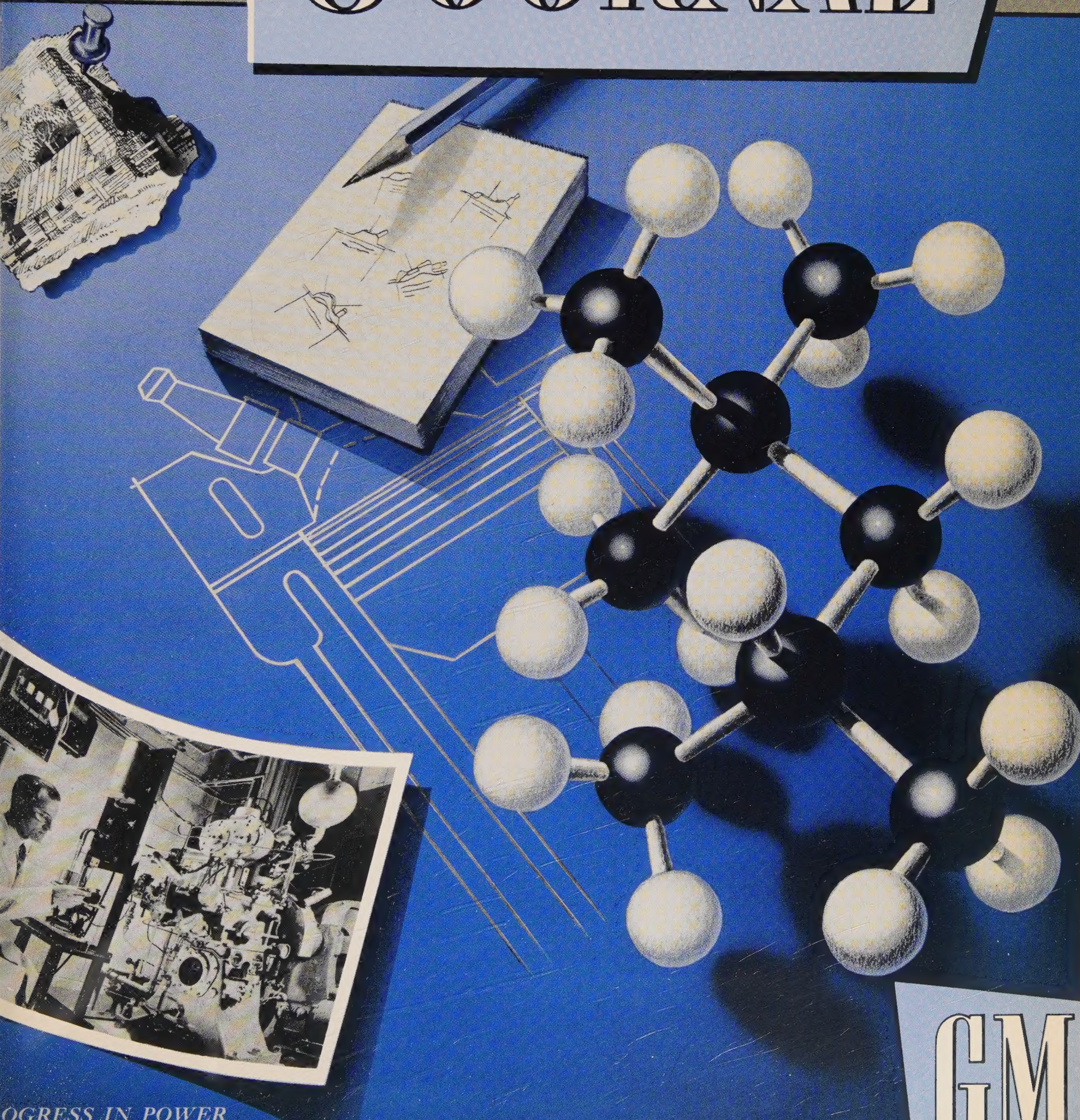
Engineering JOURNAL



OGRESS IN POWER

GM

On Being Theoretical and Practical

WEBSTER DEFINES the student as an "attentive and systematic observer." According to this description, most of us remain students all our lives, extracting knowledge from daily living experiences.

For some, the role of a student is a formal one, as with those studying in our colleges and universities. Yet no university, no matter how extensive its curriculum or how efficient its faculty, pretends to train the student for *every* situation he will meet in industry. Like prudent parents who realize the best preparation they can give their children for adulthood is to provide them with firm foundations of good principles and high ideals, the wise university endeavors to equip its students with a thorough classroom and laboratory understanding of the universal principles of the sciences. This applies particularly to engineering instruction.

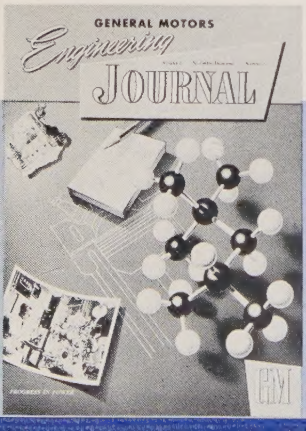
This thought was epigrammatically stated by the late Joseph Baker Davis, associate dean of engineering at University of Michigan until 1910. Dean Davis, who earned his degree in the 1860's and devoted his entire career to engineering education, put it this way: "Young man, when theory and practice differ, use your horse sense." The words are graven on a plaque to his memory on the campus.

Dean Davis' epigram symbolizes an educational point of view with which we in General Motors are in complete agreement. He implies that theories must be thoroughly understood because, most of the time, the theoretical approach applied to engineering problems succeeds. But he also implies that the other cases, where practice seems to contradict theory, demand a measure of what Dean Davis labels "horse sense." He reminds us that a student's knowledge of theory, no matter how complete, is not enough in itself. The young engineer must also use his inherent reasoning ability to solve many of the technical problems he encounters.

I would presume that Dean Davis—were he to rephrase his epigram today—would revert to the older and non-colloquial form: *horse sense* would become *common sense.* Since his time, automotive engineering has largely replaced the horse and I wonder how many young people today fully appreciate this meaning of the term horse sense. Still, it was horse sense in the laboratories and the factories that designed, perfected, and mass-produced the internal combustion engine which freed the horse from most of his burdens. The kind of horse sense which Dean Davis urged in his classrooms provided us with the machinery and harnessed the raw materials so that we have become the greatest productive nation on earth. This common horse sense still exists in the classrooms, laboratories, and factories as the nation's education and technology move ahead in unity.

C. A. Chayne

Charles A. Chayne
Vice President in
Charge of Engineering Staff



THE COVER

In the second of a cover series on "Progress in Transportation," Artist John B. Tabb's brush portrays the interdependence of the separate technologies of the automobile and petroleum industries. The beginning of the modern petroleum industry is represented by the first commercially productive oil well, sunk near Titusville, Pennsylvania, in 1859. Current automotive research and engineering emphasis on fuels are symbolized by the scientist studying fuel combustion in a single-cylinder test engine. The model shows the molecular structure of iso-octane, which has exceptionally good anti-knock properties and is used as a standard to determine the chemical octane rating of fuels. The background symbolically portrays engineers' constant search for mechanical improvements to take advantage of, and to emphasize the need for, improved fuels.

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Facilities and Operations of the General Motors Engineering Staff

(Third of a Series on GM organizations)

By LYLE A. WALSH
General Motors
Engineering Staff

Its activities
touch all GM
technical operations

The Engineering Staff of General Motors is only one of the groups contributing to the engineering of General Motors products. In line with General Motors policy of decentralization of operations and responsibilities with central coordination and control, the various manufacturing Divisions have the main responsibility for the engineering of their products which include many types of passenger cars, trucks, buses, household appliances, engines, aviation products, and defense projects. The Engineering Staff supplements this product development work of the Divisions and also helps coordinate the Divisional engineering programs. The solution of the multitude of engineering problems in the Corporation and the coordination of this work into an overall engineering program is possible because of the organization of General Motors engineering activities and the relationship of the Engineering Staff to the Divisional engineering organizations.

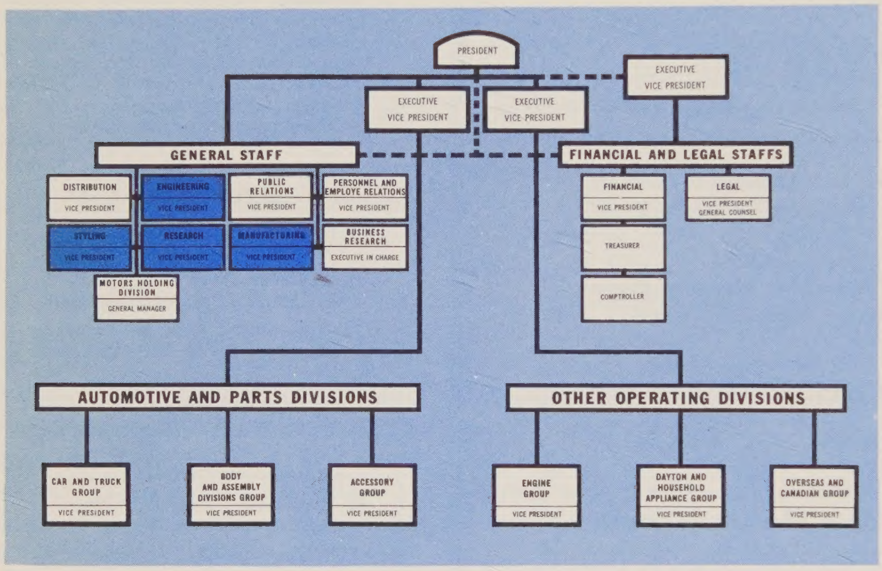


Fig. 1—General Motors Corporation organization chart showing relationship of various Staff and operating Groups.

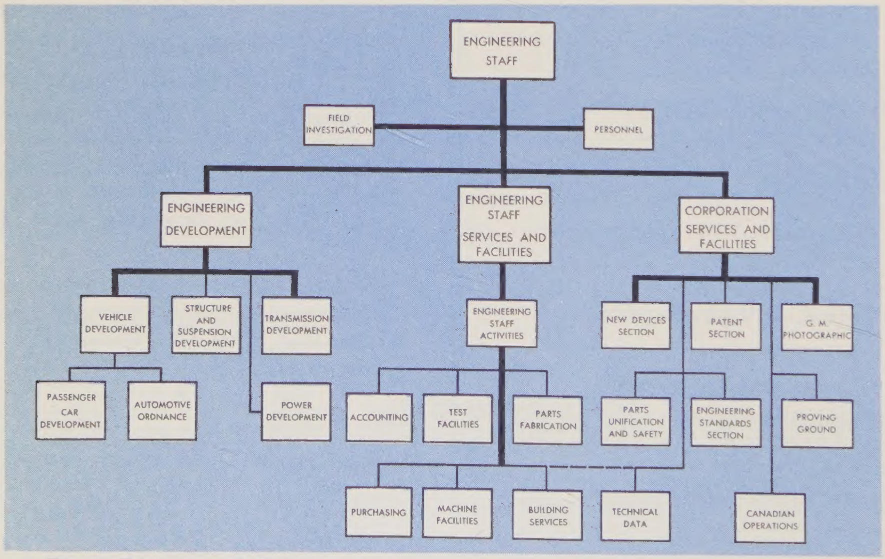


Fig. 2—Engineering Staff organization chart showing separation between development and service Groups.

The General Motors Engineering Staff maintains several engineering service *Groups* and supplements the product engineering activities of the Divisions. To understand the manner in which this dual role of the Engineering Staff is carried out requires some knowledge of the General Motors organizational setup (Fig. 1). The control of the overall engineering policy of General Motors is by recommendations of the Engineering Policy Group of the Administration Committee with the vice president in charge of the Engineering Staff as chairman of the Engineering Policy Group. The Engineering Policy Group reviews proposed major departures from current engineering practice suggested by the Divisions and also makes the final recommendations on any major new engineering programs such as new car models.

The Administration Committee, presided over by the president of General Motors, is composed of members of the Operations Policy Committee and the general managers of the car, truck, and body Divisions, plus the general managers of the General Motors Overseas Operations and Allison Divisions. The function of this Committee is to present recommendations to the Operations Policy Committee which acts for the Board of Directors in determining operating policies. There is also an interchange of engineering information between the Divisions of General Motors by means of various committees. The most important of these from the product engineering standpoint is the General Technical Committee which consists of the chief engineers of the car, truck, and body Divisions and the engineering executives of the General Motors Central Office with the vice president in charge of the Engineering Staff acting as chairman. Regular meetings held by this committee provide an opportunity for the Divisional chief engineers to bring up problems of mutual interest and also to present their viewpoints regarding future engineering policy.

The Engineering Staff is one of four Central Office Staff organizations which supplement and assist in the Divisional development programs. The other three are Research, Styling, and the Process Development Section of the Manufacturing Staff. The organization chart (Fig. 1) gives an indication of the definite separation between these staff activities and the Division operations. The staff heads may deal directly with the executives in the Divisions. They do not, however, issue any instructions nor do they have any authority over the personnel of the Divisions. The Engineering Staff works on forward GM engineering policies and coordinates the product programs of Divisions. This staff also carries out engineering studies of new products and of new engineering developments of existing products which are beyond the basic research stage. The work is independent of, yet supplemental to, the work of the Divisions, which are generally not in a position to undertake long-range projects.

A recent survey showed that more than 20,000 technical and non-technical employes are connected in some manner with the engineering development program of General Motors. Approximately ten per cent of these employes are connected with the General Motors Engineering Staff.

Engineering Staff Activities

The work of the Engineering Staff is divided into three parts: (a) Engineering Development, (b) Engineering Staff Services and Facilities, and (c) Corporation Services and Facilities (Fig. 2). All of the Engineering Development Groups as well as the Engineering Staff Services and Facilities Groups which support the Development Groups are located at the General Motors Technical Center, north of Detroit. Most of the Corporation Services and Facilities Groups have special facilities in other locations.

The Engineering Staff Development Groups were originally organized by General Motors to investigate new engineering developments such as independent suspensions, new types of transmissions, and other engineering ideas which had been proved through the research stage but which were not yet sufficiently developed to receive consideration by the manufacturing Divisions which were busy with their current production and new model programs. The Divisions are free to work on long-range development projects but such work is very expensive and generally of advantage to the Corporation as a whole rather than to one particular Division. Consequently, the Divisions generally prefer to have the long-range development work done by the Central Office rather than use their own engineering resources which may be fully occupied with their immediate programs.

The Development Groups are engaged in constant research and study in their specialized fields, contacting each other and the Division engineering staffs as required. When preliminary engineering studies have reached a sufficiently promising stage, steps are taken to initiate an active project covering the designing, building, and testing of working samples.

There are four Engineering Development Groups: Vehicle Development, Structure and Suspension Development, Transmission Development, and Power Development. The Vehicle Development Group is subdivided into a Passenger Car Section and an Automotive Ordnance Section. Of the three classifications of Engineering Staff activities located at the Technical Center, the Engineering Development Groups constitute the largest activity.

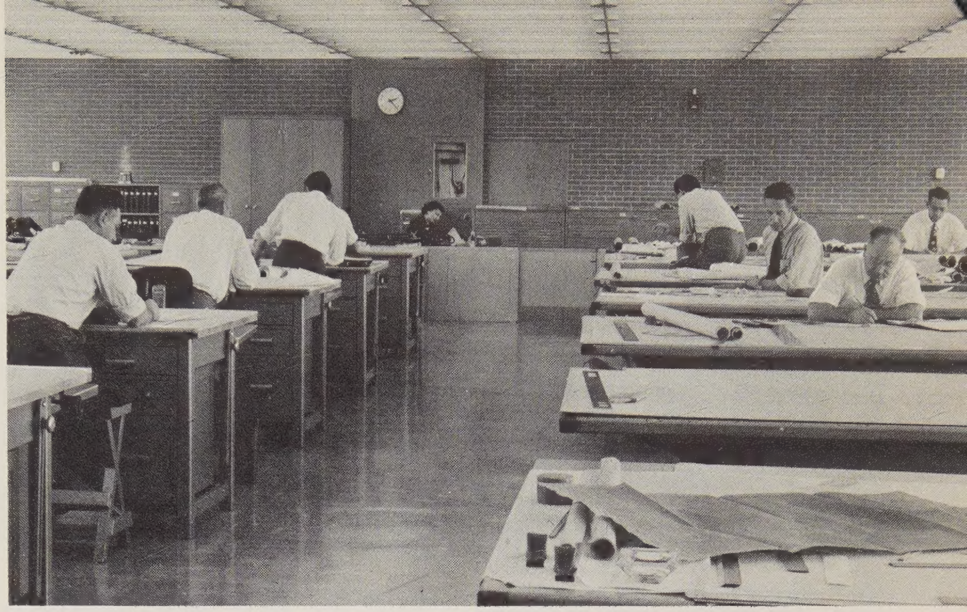


Fig. 3—Typical drafting room of an Engineering Development Group.

Vehicle Development—Passenger Car Section

The Car Development Section studies general passenger car development and devotes its efforts to the designing, building, and testing of new and advanced designs of automobiles. It also does special work for the Divisions when requested and occasionally handles the fabrication of experimental cars or parts for other Groups. Some of the experimental cars designed and built by this Group were put into production in General Motors Adam Opel Plant in Germany, the General Motors Vauxhall Plant in England, and—more recently—the General Motors Holdens' Plant in Australia. This Group also has built and is continuing to build experimental cars of novel design. In building these unconventional cars it is not the intention to design a car which will be adopted for production by a specific Division, but rather to investigate some particular feature such as a new type of suspension, a unique body construction, or a novel engine position—with the idea of developing some fundamental information on the subject which will be available to GM car Divisions (Fig. 3).

Vehicle Development—Automotive Ordnance Section

The Automotive Ordnance Section of the Vehicle Development Group is a specialized activity which was organized during World War II to contribute to the defense effort through the preliminary layout and design of military vehicle components. This Group did the

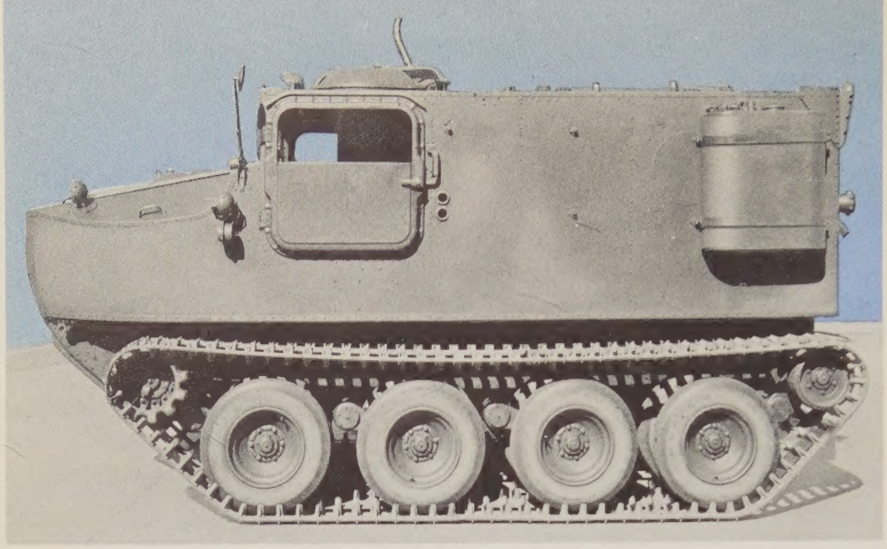


Fig. 4—Pilot model of the Otter Amphibious Cargo Carrier which was designed and developed by an Engineering Staff Group under contract with the U. S. Army.

preliminary work and built experimental models of several vehicles, both wheeled and track-laying, which were approved by Ordnance and were later produced in quantity by General Motors Divisions. The Otter Amphibious Carrier, being produced by Pontiac Motor Division, is a recent development (Fig. 4).

Structure and Suspension Development

The Structure and Suspension Development Group contributed the preliminary development work on the independent suspensions adopted by GM in the early 1930's. In addition, it is responsible for many suspension contributions to military vehicle development programs. This Group also investigates chassis, body, and engine mountings, and studies their individual and collective effects on the ride, handling, and vibration characteristics of a car.

Structure and Suspension Development engineers have designed various means of putting a car's suspension system under scientific laboratory scrutiny with the car in action. This permits the engineers to duplicate any road surface condition which an automobile might encounter and provides for the use of electronic instruments to give precise information about the effects of vibration on the parts studied (Fig. 5).

Transmission Development

The Transmission Development Group conducts an extensive engineering and development program in the fundamental research of hydrodynamic, hydrostatic, and other power transmission mechanisms. This program in the past has produced the basic designs for both the Hydra-Matic and Torque Converter type transmissions. This Group has done transmission development work on military vehicles—both wheeled and track-laying. Transmission Development has a continuing research program on many types of experimental transmissions to bring about still further refinements in present automatic transmissions (Fig. 6).

Power Development

The function of the Power Development Group is to make a long-range study of basic power plants, controls, and accessories for both commercial and military use. Its main activities consist of new approaches in design to improve efficiency and reliability, and to reduce manufacturing cost and weight.

Power Development is equipped to design, build, and test engines and accessories; likewise it designs and builds equipment for special test purposes. This Group also has contributed details of engine designs to the car Divisions and has developed complete engines both for the armed services and for future consideration by General Motors Divisions (Fig. 7).

Engineering Staff Services and Facilities

The second basic activity of the Engineering Staff, known as Engineering Staff Services and Facilities, is devoted to supplying the various operating supplies and services required by the Engineering Development Groups just described. Three of the Groups—Purchasing, Accounting, and Building Services—deal solely with the operation of the Engineering Staff Groups located at the Technical Center. They are charged with the responsibility of obtaining the necessary supplies, handling of all banking and bookkeeping, and maintaining of buildings and equipment as required to maintain Engineering Staff operations at the Technical Center. Three other Groups—Test Facilities, Machine Facilities, and Parts Fabrication—supply services to various Divisions of the Corporation as well as to Engineering Staff Groups.

Test Facilities

It is the function of the Test Facilities Group to supply space, equipment, and personnel to the various Development Groups of the Engineering Staff and to some of the Divisions for specialized testing of automotive components. Specialized testing operations are performed by each of Test Facilities' three basic Groups: Road and Dynamometer Tests, Dynamometer Laboratories, Proving Ground Operations.

Machine Facilities

The Machine Facilities Group furnishes the Engineering Development Groups with regular and emergency machine shop services or repairs, and performs work on engineering changes and on confidential projects. Inspection work also is done for the various Development Groups.

Parts Fabrication

The Parts Fabrication Group maintains fully equipped wood, metal and plastic model and engineering shops, staffed with the best craftsmen available. The Group is capable of taking on, at short notice, any emergency program demanded by the Corporation, either by furnishing assistance to a Division or by taking responsibility for a complete body building program.

The primary function of Parts Fabrication consists of serving the Engineering Staff Development Groups. Any open time not used by the Engineering Staff is made available to the Styling Section, to Fisher Body Division, or to any other Division requesting available services. In addition to the building of experimental bodies and other parts for the Development Groups, this Group builds full-size experimental bodies for the Styling Section, Fisher Body Division, and other Divisions. Special work done

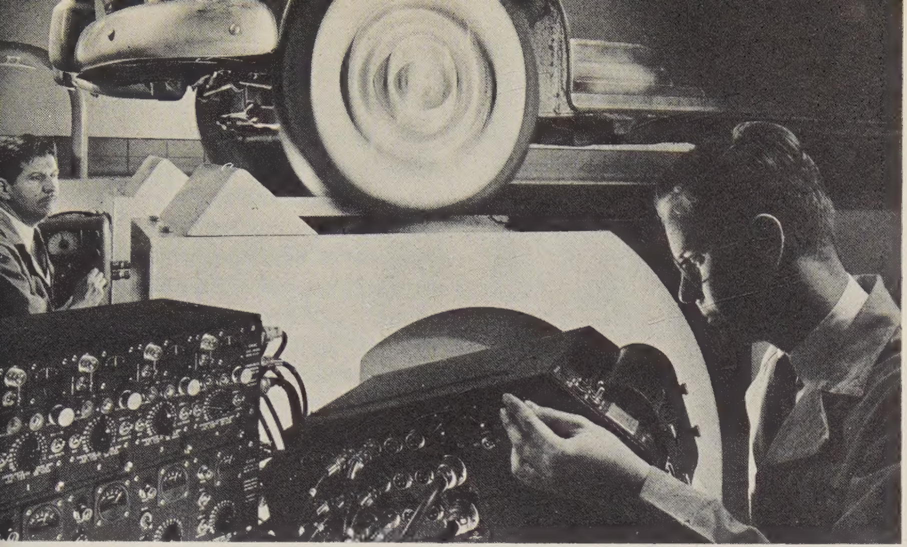


Fig. 5—Use of a recording oscillograph in laboratory suspension analysis provides a permanent record of high-speed action.

by this Group includes much of the development of glass reinforced laminated plastic for use in model and body building and also high precision aluminum and stainless steel work used in connection with General Motors aircraft jet engine production.

Corporation Services and Facilities

The third principal activity of the Engineering Staff—Corporation Services and Facilities—contributes, in general, to the Divisional development programs by furnishing specialized services to the Divisions either as a matter of routine or upon request. Under this activity, there are a number of separate organizations including the New Devices Section, Engineering Standards, Technical Data, Canadian Operations, Vehicle Safety, Patent Section, GM Photographic, and the Proving Grounds.

A description of a few of the activities of these groups illustrates typical services performed for General Motors by this particular activity of the Engineering Staff.

New Devices Section

Because of the legal problems involved, it is the policy throughout General Motors that any new devices, designs, or suggestions submitted by outsiders be routed through the New Devices Section. It is the responsibility of the New Devices Section to investigate these submissions, making certain that the rights of the Corporation are fully protected, handling all correspondence and contacts in such a way as to earn the good will of the individuals concerned, and referring those devices which are worthwhile to the attention of the General Motors Divisions that may be interested. Another responsibility of this Section is to act as liaison in patent matters between the Engineering Development Groups and the Patent Section.

Patent Section

The Patent Section is responsible for all patents, trademark, copyright, and related matters affecting General Motors or its subsidiaries here and abroad. It obtains all patents for the Corporation and registers all trademarks and copyrights. It advises whether products and machines or methods of manufacture infringe any patents and whether trademarks infringe the rights of others. It answers all charges of infringement, handles all patent, trademark, and alleged confidential disclosure litigation, and advises action to be taken in cases of infringement of Corporation-owned patents and trademarks. It negotiates and prepares, in collaboration with the managers of the interested operations and staff executives, agreements and options for the purchase, sale, or licensing of inventions, patents, trademarks, or copyrights or for the purchase or sale of engineering information or "know-how," and advises with respect to all other contracts dealing in any way with such matters.

GM Photographic

Since 1919, when it was organized as a blueprint department, General Motors Photographic has operated as a service organization for General Motors and its Divisions. Today it employs nearly 700 persons. Its functions and facilities are divided into four basic Groups: Photographic Reproduction, Printing, Art, and Merchandising Aids.

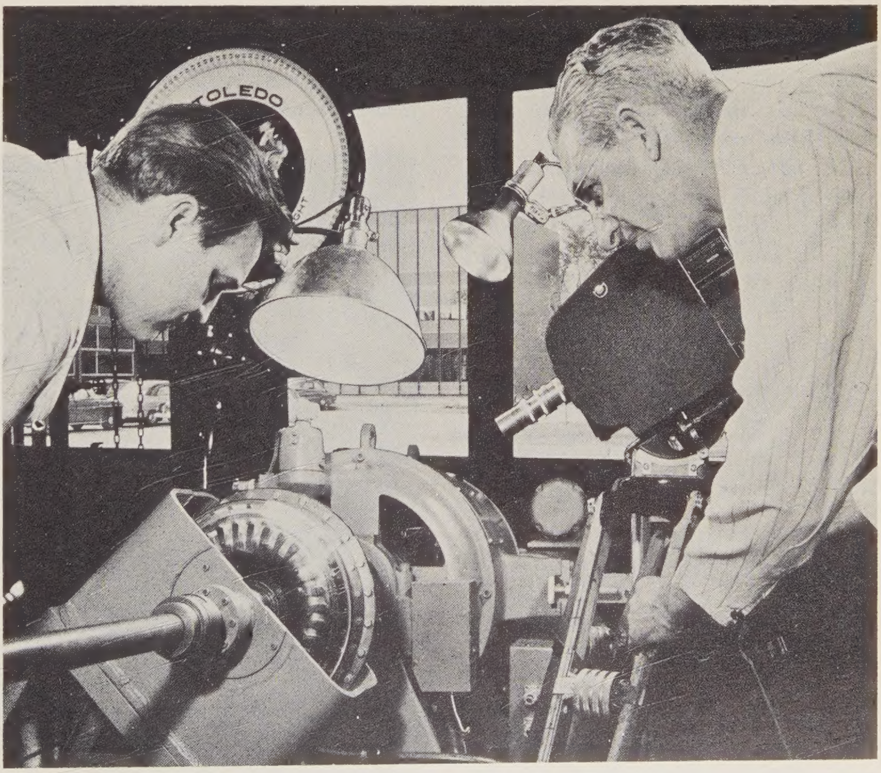


Fig. 6—Using a torque converter with a plastic housing and a motion picture camera operating at 7,000 frames-per-second in the study of fluid flow and converter blade design.

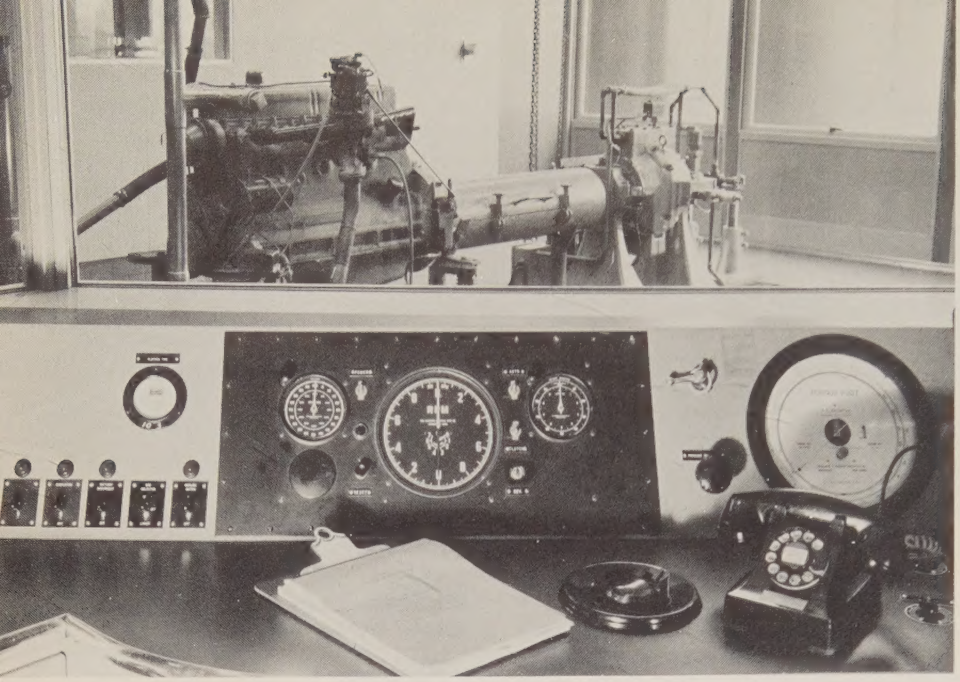


Fig. 7—Engine durability test room, showing control panel in foreground with engine and dynamometer in rear.

The Photographic Reproduction Group engages in a wide variety of specialized photographic activities, the scope of which is indicated by a listing of its various sections. These include blueprint, photostat, commercial photography, motion picture and slide film, chart master, microfilm, template and tracing reproduction. The services of the Photographic Reproduction Group apply to all activities of the various Divisions, from research to sales.

The Offset Printing Department provides printed materials for the various Divisions and Sections of the Corporation. Its printing plant, air conditioned to assure extreme printing accuracy, is one of the most modern in the country. It has facilities for handling practically all types of offset printing requirements.

The Art Department maintains a staff of several artists with diversified talents to render mechanical and pictorial illustrations, creative layout, lettering, and design.

The Merchandising Aids Department is primarily involved in programmed materials for the various car and truck Divisions and their dealers. Its activities cover the fields of service, wholesale parts and accessories—as well as product promotion.

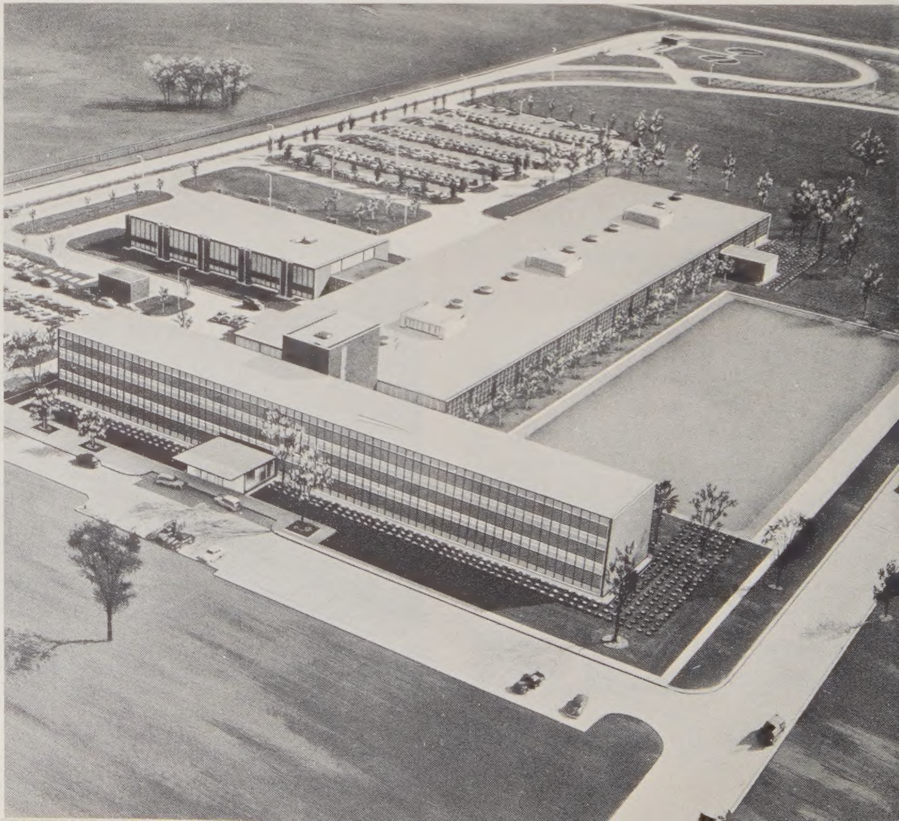


Fig. 8—Aerial view of Engineering Staff buildings located at GM Technical Center.

In addition to its regular services, General Motors Photographic is also engaged in a constant study of new methods to improve the quality and lower the cost of reproduction work.

Other Groups

The Engineering Standards, Technical Data, Canadian Operations, and Vehicle Safety Groups all work with the various Divisions of General Motors to investigate and coordinate General Motors operations in their particular phase of activity.

General Motors Proving Grounds

The Proving Grounds have three major functions as a service organization to the Corporation. The first is to provide and maintain a system of private roads available to the automotive and accessory Divisions for development of their products and adequate for the study of engineering problems. Included in this responsibility is the provision of garage space and service facilities. The second responsibility is to purchase, each year, a fleet of production cars, both General Motors and competitive, to be subjected to a comprehensive engineering test program so that the characteristics and quality of General Motors cars may be evaluated in comparison with those of the rest of the industry. The third function is to assist in the development programs of the Divisions by conducting, at their request, special tests for which the Proving Ground test facilities and experience are particularly fitted.

Facilities

The facilities of the various Engineering Staff Groups are particularly well fitted to carry on the responsibility of assisting the engineering Groups of the manufacturing Divisions in basic engineering studies as well as to carry on independent engineering projects.

Development and Staff Services Facilities

In the new Engineering Staff buildings at the General Motors Technical Center, the Engineering Staff Development and Services and Facilities Groups have the best possible engineering facilities as well as an ideal environment for creative work (Fig. 8).

The three-story Engineering Staff office building, 50 ft wide and 365 ft long, is a functionally modern building with unique structural features permitting maximum flexibility of office space. The special truss and exterior wall columns permit the use of the full width of the building without any obstructing columns. The arrangement of the building with elevators, stairwells, and rest rooms on the south side also provides the maximum of north light through the double pane windows. This, with a new type of high efficiency fluorescent lighting system, has resulted in the best in drafting room lighting.

The Engineering Staff shop, located directly south of the office building, designed for maximum utility, flexibility, and safety, is 160 ft wide and 570 ft long, with only a single row of columns down the center. Partitions along the central corridor are arranged so they form a permanent wall or may be opened at any point for movement of vehicles. An extensive overhead crane system is provided so that electric hoists are available at almost any point in the building. Water, air, and electrical outlets have been located at regular intervals in utility panels to provide maximum flexibility and to avoid high expense and delays in departmental rearrangements.

The dynamometer building, 100 ft wide and 180 ft long, is designed to cover the wide range of special tests encountered in development work. It includes 12 test cells primarily for engine and transmission work and one double cell for heavy transmission, drive-line, and engine testing. A two-story test cell is equipped with power rolls and special equipment for bump and shake tests of complete vehicles. A special chassis test room is equipped with full dynamometer equipment including inertia weights and provisions for air blast and temperature controls to allow torque testing of vehicles under road conditions. There is also an electrically-shielded room large enough for complete vehicles and a carburetor flow room for fuel system development work.

Extra safety precautions are installed in the dynamometer building to provide the optimum in protection. Each test cell has a separate exhaust system. Air enters the cell through the ceiling in the form of a curtain around the test area shielding the operator from engine heat and fumes. Fuel tanks and a gasoline blending house are located separately from the dynamometer building. These facilities, as well as test cells, are protected by both an automatic carbon dioxide system and hand extinguishers. In addition, there is an arrangement for the automatic stoppage of fuel flow from the blending house in case of emergency.

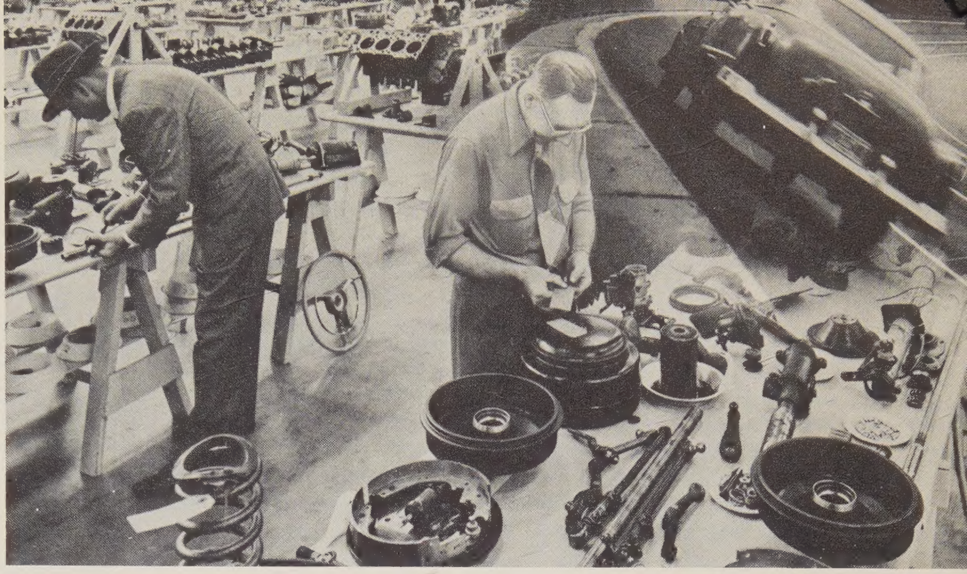


Fig. 9—The engineering audit—final comparison of cars and parts at the General Motors Proving Ground after completion of the 25,000-mile durability tests.

Corporation Services Facilities

The Engineering Staff Groups supplying engineering services to General Motors as a whole also have specially developed facilities to carry on their work. The specialized facilities of the three General Motors Proving Grounds are particularly noteworthy.

The original Proving Ground, at Milford, Michigan, has over 1,500 acres and 30 miles of roads and is devoted primarily to the testing of cars, trucks, and other commercial vehicles. The facilities include a 3.8-mile test track, hard-surface straightaway check roads, as well as specialized test surfaces such as cobblestone, asphalt, gravel, and test hills of various grades (Fig. 9). Garage facilities and laboratory test facilities are also maintained for the use of the Proving Ground Staff and the various General Motors Divisions.

The Military Proving Ground, adjacent to the Commercial Proving Ground, consists of 1,000 acres with a separate road system and buildings for test work on various types of military vehicles built by General Motors. In addition to the rugged road system designed to duplicate actual service conditions, specialized test equipment is available to meet the requirements of the military vehicles tested at this facility.

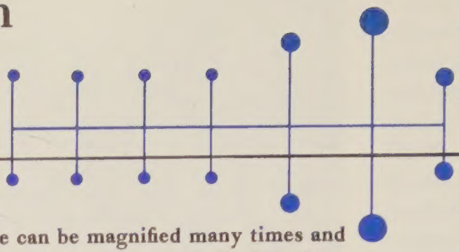
A major expansion of test facilities was provided by the completion of the 2,280-acre Desert Proving Ground near Mesa, Arizona. Here the much-needed facilities are available for conducting development work under conditions of high temperatures and dry or dusty atmospheres. The road system, all hard-surfaced, consists of a five-mile circular speed loop and a straightaway one and one-half miles long.

Summary

While the Central Office Engineering Staff is only a part of General Motors' vast research and engineering organization, it makes important contributions to the General Motors engineering program. With the improved facilities available at the three General Motors Proving Grounds, the new General Motors Technical Center, and at other locations, the Engineering Staff is equipped to contribute still more to General Motors product engineering progress. Its efforts to supplement the independent engineering operations of General Motors Divisions have resulted in:

- Continued development of existing products
- Finding new applications for existing products
- Development of new products
- Development and use of new and better materials.

Torsional Vibrations in Diesel Engines



By **CHRISTIAN G. GOOHS**
Cleveland Diesel Engine Division

How applied physics helps engineers avoid critical speeds

The engine designer knows that a small varying torque can be magnified many times and cause serious vibrations without the operator suspecting their existence until the effects are more or less damaging. These unique disturbances, called torsional vibrations, may be a hidden menace to engines. Though the results are hidden, it is fortunate that application of well-known theory and equations can predict their occurrence at certain critical speeds. Then, if these speeds are in the normal rpm range of the engine being designed, theoretical solutions which may or may not involve countering mechanisms may be introduced into the design.

DURING the early part of this century, numerous apparently unexplainable crankshaft failures in reciprocating steam engines brought to light a phase of engineering practically unknown to the engine designer. Conventional stress calculations indicated that the components of these engines were exceptionally strong and that the failures could not have been caused by engine torque, shaft loading, or misalignment. Further investigations of the failures showed that they were caused by *torsional vibrations*. These vibrations were torsional oscillations super-imposed on the normal rotation of the shaft system, and, when operating *at resonance*, would often cause shaft failures.

Although this phenomenon was first recognized in reciprocating steam engines, it wasn't long before it was discovered to exist in all reciprocating engines. This was especially true of Diesel engines with their high torque irregularities. Failures in all types of drives—such as those in generators, marine engines, automobiles, and aircraft—showed further need for the study of torsional vibrations.

With the demand for higher horsepower Diesel engines, engines were built with higher operating speeds, increased brake-mean-effective-pressures (*bmep's*), and a greater number of cylinders. All of these aggravated a serious condition by increasing the number of *critical*, or resonant, speeds as well as the amplitudes of these vibrations.

Even though the present-day Diesel engine designer has a better understanding of this vibration problem, he is still plagued with many troubles resulting from torsional vibrations. The impact loading of gears, the loosening of generators on shafting, and the failure of ball bearings are recurring problems to the designer.

The continued use of high output internal combustion engines establishes the need for a thorough torsional vibration investigation, especially during the design stage of an installation. If mathematical calculations are made and the existence and location of serious torsional vibrations are pre-determined, the necessary design changes can be made, thereby preventing costly changes or failures. The present-day knowledge of torsional vibration analysis has progressed to this point, but an accurate analysis requires the expenditure of considerable effort and time.

The problem of torsional vibrations is sufficiently well understood that torsional critical speeds and torsional amplitudes can be pre-determined with reasonable accuracy during the design stage of an engine development. Often, a speed range free of serious critical speeds is made possible by the use of torsional vibration dampers or torsional elastic couplings. Their proper use in an engine installation either dampens the vibration or locates the critical speeds below the normal operating speed range.

Those torsional vibrations or critical speeds which, upon investigation, show large amplitudes of vibration or large vibratory torques can produce disastrous effects on some part of the mass-elastic or torsional system. Operation at a critical speed is not always obvious to the operator since warning signs are seldom present. However, at some violent critical speeds the engine shudders or the gears become noisy. Also, a change in the overall engine noise level sometimes discloses operation at a critical speed.

Sometimes the gear noise that is present when operating at a critical speed is due to the large vibratory torques on the gears. When the vibratory torque is greater than the transmitted torque, the gear mesh separates or breaks contact during each cycle of vibration and gear clatter results. The impact loads may even cause tooth failure.

The large vibratory torques present during a critical-speed operation also may be sufficient to set up high stresses which may result in failures as with the steam-engine crankshafts. It must be remembered that these stresses are vibratory in nature and the number of cycles of stress imposed per second is equal to the vibration frequency. Such shaft failures are without a doubt costly to the operator in lost time, money, and inconvenience.

Large torsional amplitudes in a Diesel engine generator system also may cause damage to pressed-on armatures by loosening the hubs on the shaft or even breaking off pole pieces. Excessive cyclic irregularities can also exist due to large vibratory amplitudes at the generator and result in poor electrical frequency regulation. Camshafts and accessory drives may fail due to large vibratory amplitudes and stresses. Failure of driving keys, armatures, flywheel spokes, and ball bearings often can be attributed to torsional vibrations.

Fundamentals of Torsional Vibrations

In order to understand how torsional vibrations affect Diesel engine design, it is of paramount importance to understand the theory of vibrations. It is difficult to visualize these vibrations since

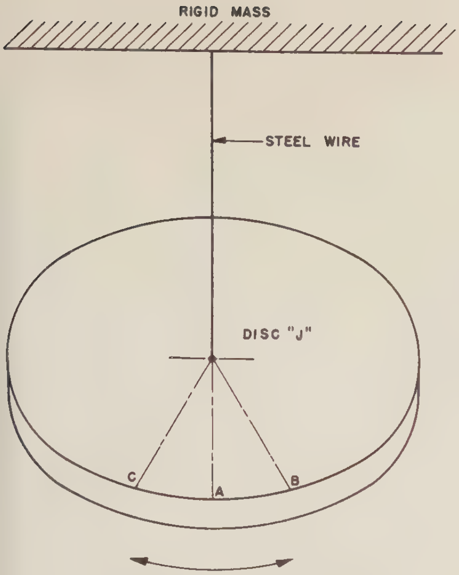


Fig. 1—Simple torsional pendulum.

they act in a twisting manner while the shafting is rotating and therefore cannot be directly observed except by special instrumentation. The layman usually confuses torsional vibrations with lateral vibrations, engine unbalance, crankshaft whirling, or some other visible or noticeable vibration.

To illustrate torsional vibrations, Fig. 1 shows a small disc suspended by a thin steel wire. If the disc is given a rotary twist from *A* to *B* and then released, the elasticity or stored energy of the wire returns the disc to its neutral position *A*. However, the energy stored in the disc due to acceleration causes the disc to travel past the neutral position *A* and continue on to position *C*. Thus, if there were no inherent friction in the wire, the disc would continue to oscillate successively from *B* to *A* to *C* to *A* to *B*, etc., indefinitely. However, since friction or hysteresis is always present, the arc of each successive oscillation becomes smaller until the disc finally stops on position *A*. For practical purposes, the time required for each oscillation remains the same regardless of the magnitude of the arc of oscillation. The first fundamental law of vibration states that every mass-elastic system has at least one definite or natural frequency at which it vibrates. The period or time of oscillation can be changed by altering either the rigidity of the wire or the polar moment of inertia of the disc.

The normal concept of steel shafting is that it is perfectly rigid. If this were true, the entire rotating shaft system with attached masses would accelerate as a solid unit when torque was applied. It also could be said, if the shafting were perfectly rigid, that the only effect of a varying torque on the entire mass system would be to vary the speed of the entire system.

Since steel shafting is elastic, however, the vibrating mass system can be considered as a system of flywheel masses connected by elastic springs. When under the influence of an impressed torque variation, the shaft system does not accelerate as one unit but instead the various masses accelerate and decelerate according to the elasticity and torque distribution between the masses and connection shafting, thereby creating torsional disturbances or vibrations.

Now consider the two-mass system of Fig. 2. Two flywheels are connected by a steel shaft and supported on bearings. If flywheel *J1* is held stationary while torque is applied to flywheel *J2* and both flywheels are then released simultaneously, the two flywheels oscillate in opposite directions and both reach the outer extremity of their angular motion at the same instant. They continue to oscillate angularly in this manner at a definite natural frequency but through successively decreasing arcs. It is possible now to visualize that this same torsional vibration can exist while the flywheels and shaft are actually rotating.

It can also be seen that torsional vibrations of a shaft system are the result of a periodic varying torque acting on the shaft system in synchronism with one of its natural frequencies.

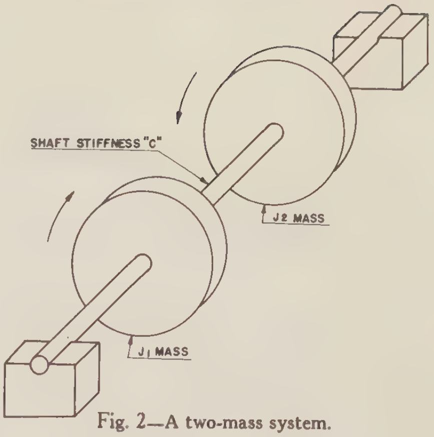


Fig. 2—A two-mass system.

Although no attempt is made in this paper to show the detailed computations required for making a torsional vibration analysis, an understanding of the problem may be gained by considering an example using a typical four-cylinder, two-cycle Diesel engine direct-coupled to a flywheel and a-c generator (Fig. 3). The unit is rated at 150 kw at 1,200 rpm constant speed. Five important aspects of the normal torsional vibration analysis will be considered as follows:

- The equivalent mass-elastic system
- Natural frequencies
- Critical speeds
- Amplitudes and stresses
- Corrective measures.

Equivalent Mass-Elastic Systems

As already mentioned, the theory of torsional vibrations is based on a simple system of masses connected by means of elastic shafting which is assumed to be without mass. In actual practice, the systems are much more complex and some simplification is required for purpose of analysis. In order to solve an actual torsional problem, the analyst attempts to mathematically replace the actual complex system by an ideal system which retains as nearly as possible the dynamic and elastic characteristics of the original complex system. The accuracy of calculating the ideal or equivalent mass-elastic system is particularly important for the higher modes of vibration since small changes in mass or stiffness materially affect the location of the higher frequencies of vibration.

This general theory is applied to the four-cylinder installation shown in Fig. 3. Fig. 4 shows the arrangement of the shafting and weight-radius details of this

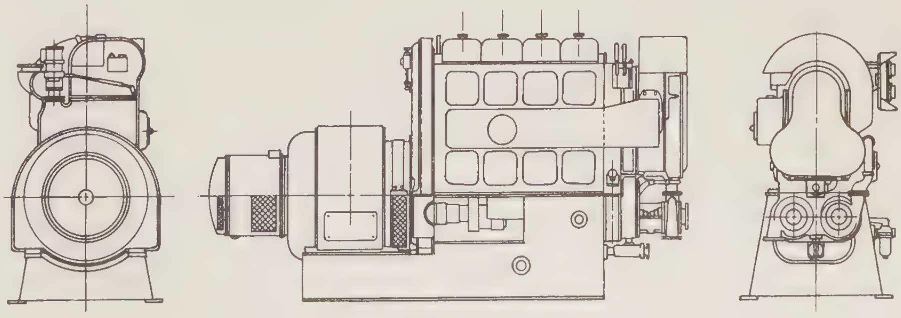


Fig. 3—Four-cylinder, two-cycle Diesel generator set.

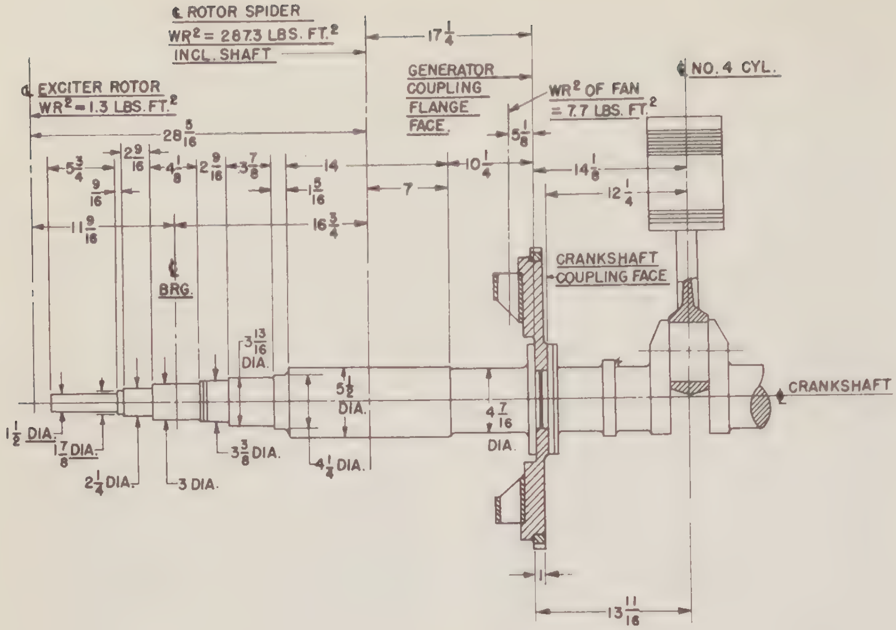


Fig. 4—A four-cylinder, in-line, two-cycle Diesel engine direct-connected to a generator.

unit. The actual system can be replaced with an equivalent system of seven masses as shown in Fig. 5. The polar moment of inertias of the masses are calculated by the basic equation:

$$\frac{WR^2}{g} = J$$

where
W = weight of the mass
R = radius of gyration of the mass
g = acceleration of gravity
J = polar moment of inertia of the mass

The stiffness or torsional rigidity of the shafts can be calculated by the basic equation:

$$C = \frac{GH}{L}$$

where
C = torsional rigidity of the shafting
G = modulus of rigidity
H = polar moment of inertia of the shaft cross-sectional area
L = shaft length.

Calculation of Natural Frequencies

Recall that every system of masses connected by torsionally elastic shafts has at least one *torsional natural frequency.* Torsional natural frequency may be defined as the number of periodic torsional oscillations or cycles at which a system vibrates at maximum amplitude when acted upon by a periodically varying torque. Any torsional system has *n-1* natural vibrating frequencies, where *n* is the number of masses attached to the shaft system.

The differential equation for the motion of a mass system with a single degree of freedom, such as a disc suspended on a wire or slender rod and supported in bearings, is:

$$J\frac{d^2\Theta}{dt^2} + b\frac{d\Theta}{dt} + c\Theta = T_0 \sin\omega t$$

where
J = polar moment of inertia of the disc
Θ = angular displacement in radians
b = damping constant
c = torsional stiffness of shaft
$T_0 \sin\omega t$ = externally applied torque.

The terms, from left to right in the above equation, represent then the inertia torque, the damping torque, the spring torque, and the externally applied torque.

The solution of the above differential equation leads to the solution of the following natural frequency equation:

$$f = \frac{1}{2\pi}\sqrt{\frac{C}{J}}$$

where
f = natural frequency of vibration in cycles per second.

In like manner, the natural frequency of vibration of a two-mass system, as shown in Fig. 2, is:

$$f = \frac{1}{2\pi}\sqrt{\frac{C\,(J_1 + J_2)}{J_1 \times J_2}} \text{ vibrations per second.}$$

The frequency of a three-mass system, as shown in Fig. 6, also may be obtained by formulae as follows:

$$f = \frac{1}{2\pi}\sqrt{A \pm \sqrt{A^2 - B}}$$

$$A = \frac{C_1\,(J_1 + J_2)}{2J_1J_2} + \frac{C_2\,(J_2 + J_3)}{2J_2J_3}$$

$$B = \frac{(J_1 + J_2 + J_3)\,C_1C_2}{J_1J_2J_3}$$

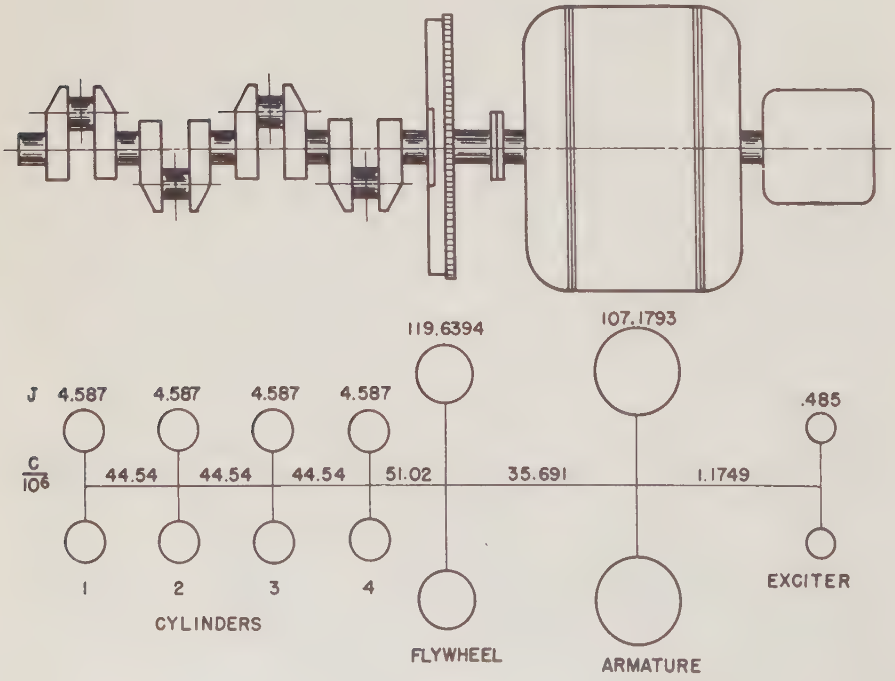


Fig. 5—Equivalent dynamic system of a direct-connected engine-generator system

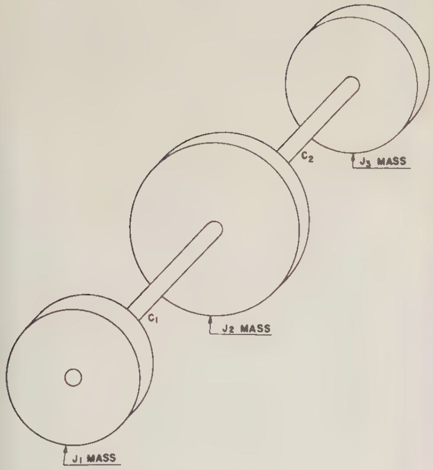


Fig. 6—Three-mass system.

As can be seen by the complexity of the three-mass-system equation, any system with more than three masses can not be calculated by simple solution.

As shown by the above equations, the natural frequency of vibration for a shaft system depends on a state of equilibrium existing between the elastic forces in a twisted shaft and the inertia torque of the vibration masses. Therefore the summation of all of the torques in the shaft system must be zero when this condition is fulfilled. A trial and error tabulation method of obtaining these frequencies was devised by Holzer. (Holzer, H., "Die Berechung der Drehschwingungen," Berlin, 1921.)

The Holzer tabulation locating the first or lowest natural frequency of vibration for the cited example is shown in Table I. Tables II and III are the Holzer tabulations for the second and third natural frequencies of vibration.

A natural frequency torsional vibration is usually identified by the manner in which the system vibrates in torsion, or in other words, the *mode of vibration.* For each natural frequency, the mass-elastic system has a definite pattern or mode of vibration, and each of these modes of vibration is described by the number of nodal points that occur in its pattern. Nodal points, or *nodes*, refer to those parts of the system which have no angular oscillatory motion or vibration (Fig. 7). Thus, the first natural frequency is commonly referred to as the one-noded mode of vibration since it has only one node or nodal point. Also, the second natural frequency is referred to as the two-noded mode of vibration, etc., for each successive natural frequency.

When considering any individual mode

$N = 119.8$ VPS
$\omega = 2\pi N = 752.727$
$\omega^2 = .566598 \times 10^6$

One-Noded Vibration

1	2	3	4	5	6	7	8
Mass	J	$\frac{J\omega^2}{10^6}$	Θ	$\frac{J\omega^2\Theta}{10^6}$	$\frac{\Sigma J\omega^2\Theta}{10^6}$	$\frac{C}{10^6}$	$\frac{\Sigma J\omega^2\Theta}{C}$
#1 Cyl.	4.587	2.5990	1.0000	2.5990	2.5990	44.54	.0584
#2 Cyl.	4.587	2.5990	.9416	2.4472	5.0462	44.54	.1133
#3 Cyl.	4.587	2.5990	.8283	2.1528	7.1990	44.54	.1616
#4 Cyl.	4.587	2.5990	.6667	1.7328	8.9318	51.02	.1751
Flywheel	119.6394	67.7874	.4916	33.3243	42.2561	35.691	1.1839
Armature	107.1793	60.7276	−.6923	−42.0417	.2144	1.1749	.1825
Exciter	.485	.2748	−.8748	−.2404	−.0260		

$N \times 60 = 7188$ VPM

4 ORDER CRITICAL 1797 RPM
8 ORDER CRITICAL 899 RPM
12 ORDER CRITICAL 599 RPM
16 ORDER CRITICAL 450 RPM

Table I—The final Holzer tabulation trial for the one-noded mode of vibration frequency.

$N = 192.26$ VPS
$\omega = 2\pi N = 1208.008$
$\omega^2 = 1.459283 \times 10^6$

Two-Noded Vibration

1	2	3	4	5	6	7	8
Mass	J	$\frac{J\omega^2}{10^6}$	Θ	$\frac{J\omega^2\Theta}{10^6}$	$\frac{\Sigma J\omega^2\Theta}{10^6}$	$\frac{C}{10^6}$	$\frac{\Sigma J\omega^2\Theta}{C}$
#1 Cyl.	4.587	6.6937	1.0000	6.6937	6.6937	44.54	.1503
#2 Cyl.	4.587	6.6937	.8497	5.6876	12.3813	44.54	.2780
#3 Cyl.	4.587	6.6937	.5717	3.8268	16.2081	44.54	.3639
#4 Cyl.	4.587	6.6937	.2078	1.3910	17.5991	51.02	.3449
Flywheel	119.6394	174.5877	−.1371	−23.9360	−6.3369	35.691	−.1775
Armature	107.1793	156.4049	.0404	6.3188	−.0181	1.1749	−.0154
Exciter	.485	.7078	.0558	.0395	.0214		

$N \times 60 = 11536$ VPM

4 ORDER CRITICAL 2884 RPM
8 ORDER CRITICAL 1442 RPM
12 ORDER CRITICAL 961 RPM
16 ORDER CRITICAL 721 RPM

Table II—The final Holzer tabulation trial for the two-noded mode of vibration frequency.

$N = 248.38$ VPS
$\omega = 2\pi N = 1560.621$
$\omega^2 = 2.435538 \times 10^6$

Three-Noded Vibration

1	2	3	4	5	6	7	8
Mass	J	$\frac{J\omega^2}{10^6}$	Θ	$\frac{J\omega^2\Theta}{10^6}$	$\frac{\Sigma J\omega^2\Theta}{10^6}$	$\frac{C}{10^6}$	$\frac{\Sigma J\omega^2\Theta}{C}$
#1 Cyl.	4.587	11.1718	1.0000	11.1718	11.1718	44.54	.2508
#2 Cyl.	4.587	11.1718	.7492	8.3699	19.5417	44.54	.4387
#3 Cyl.	4.587	11.1718	.3105	3.4688	23.0105	44.54	.5166
#4 Cyl.	4.587	11.1718	−.2061	−2.3025	20.7080	51.02	.4059
Flywheel	119.6394	291.3863	−.6120	−178.3284	−157.6204	35.691	−4.4163
Armature	107.1793	261.0393	3.8043	993.0718	835.4514	1.1749	711.0830
Exciter	.485	1.1812	−707.2787	−835.4376	.0138		

$N \times 60 = 14903$ VPM

4 ORDER CRITICAL 3726 RPM
8 ORDER CRITICAL 1863 RPM
12 ORDER CRITICAL 1242 RPM
16 ORDER CRITICAL 931 RPM

Table III—The final Holzer tabulation trial for the three-noded mode of vibration frequency.

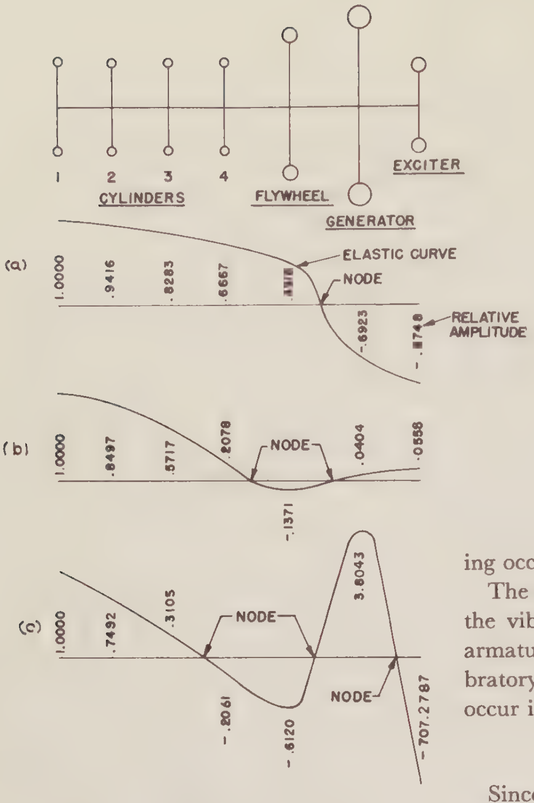


Fig. 7—Relative elastic curves.

of vibration, each separate mass has a definite torsional or angular deflection relative to the first mass. A plot of these angular deflections is called an *elastic curve*. This elastic curve is of importance since it helps one to visualize the actual vibration, and indicates the location of the nodal point.

Fig. 7 shows the elastic curves for the three modes of vibration. These deflections were plotted from column 4 of Tables I, II, and III. Thus, it can be seen that the one-noded mode of vibration is essentially the vibration of the engine and flywheel against the armature and exciter. The nodal point, or point of zero angular deflection, as shown in the change of signs from plus to minus in column 4, is in the armature shaft; also the maximum vibratory torque expressed by the value 42.2561 in column 6 is in this same shaft. It can be seen further (from the relative deflection, 1.1839, the largest value in column 7) that the maximum change in deflection also occurs in the armature shaft and, therefore, is probably the major source of damping.

The two-noded mode of vibration is the vibration of the flywheel against the engine and armature. The maximum vibratory torque, deflections, and damping occur in the engine.

The three-noded mode of vibration is the vibration of the exciter against the armature. Therefore, the maximum vibratory torque, deflection, and damping occur in the exciter shaft.

Critical Speeds

Since Diesel engines, with their high firing pressures, are particularly susceptible to serious torsional vibrations, it is important to know at what speeds these resonant conditions or critical speeds occur. Fourier's theorem states that any periodic wave form, such as the turning effort curve of a reciprocating engine, is composed of an infinite number of harmonic components with 1, 2, 3, 4, etc., complete cycles or harmonics occurring during one fundamental period, and the sum of these harmonics equals the original function, which in this case is the turning effort curve. Each of these harmonic components acts as an individual torque and can excite or force a vibration in the mass-elastic system upon which the torque is acting. Since each harmonic occurs at a fixed number of times per revolution of the engine—for example, the first harmonic order occurs once per revolution—at any definite rpm such as 1,200 rpm, the first harmonic has a frequency of 1,200 vibrations per minute, or vpm. If the natural frequency of the system is 1,200 vpm, the first order critical speed occurs at 1,200 rpm. For this same case, the second order critical speed caused or excited by the second order harmonic is at 600 rpm because it has two cycles of periodic force per engine revolution. The third order critical speed is at 400 rpm, etc. Thus, the number of vibrations that occur per shaft revolution is referred to as the *order* of the critical speed.

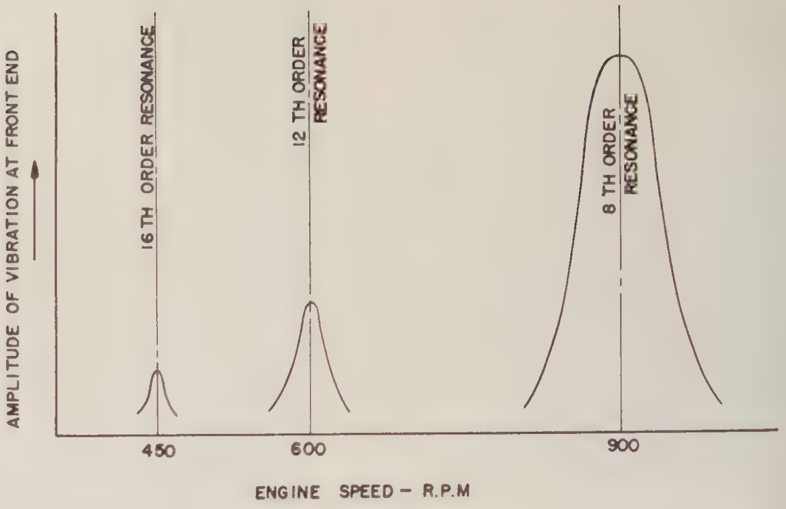


Fig. 8—One-noded mode of vibration resonance curves for a two-cycle engine.

A two-cycle engine, which has a power stroke every revolution, can excite an infinite number of orders of vibration for each mode of vibration, but only whole orders. A two-cycle engine never excites half orders or multiples of half orders. Its vibrations are of the first order, second order, third order, etc. It may be of interest to note, however, that a four-cycle engine does excite half orders, as well as whole orders.

Each normal mode of vibration has a succession of critical speeds corresponding to the harmonic orders which excite it, and each order of vibration produces a definite amplitude of torsional deflection depending on the magnitude of the exciting force. The orders of vibration, although they attain full resonance at their critical speeds, actually "force" vibrations on the system for a limited but definite range of speeds on either side of the critical speed. Fig. 8 indicates the major critical speeds and indicates the relative amplitude of the vibrations on both sides of resonance.

These curves show only the succession of critical speeds for the one-noded mode of vibration. But every multi-mass system has at least two, three, or more modes of vibration that must be considered. Every mode has a similar succession of critical speeds determined by the frequency of that particular mode of vibration. These could actually be superimposed on Fig. 8. Table IV lists the total number of possible critical speeds

ONE-NODED FREQUENCY 7188 VPM		TWO-NODED FREQUENCY 11536 VPM		THREE-NODED FREQUENCY 14903 VPM	
ORDER NO.	RPM	ORDER NO.	RPM	ORDER NO.	RPM
1	7188	1	11536	1	14903
2	3594	2	5768	2	7452
3	2396	3	3845	3	4968
4	1797	4	2884	4	3726
5	1438	5	2307	5	2981
6	1198	6	1923	6	2484
7	1027	7	1648	7	2129
8	899	8	1442	8	1863
9	799	9	1282	9	1656
10	719	10	1154	10	1490
11	653	11	1049	11	1355
12	599	12	961	12	1242
13	553	13	887	13	1146
14	513	14	824	14	1065
15	479	15	769	15	994
16	449	16	721	16	931

Table IV—Tabulation of critical speeds.

and their speed locations.

Of course, the critical speeds that require consideration are only those within the operating speed range. For example, if this engine has an operating range of 300 to 1,320 rpm the following critical speeds would require investigating:

- one-noded frequency—orders 6-16 inclusive
- two-noded frequency—orders 9-16 inclusive
- three-noded frequency—orders 12-16 inclusive

It has been pointed out that critical speeds at which large exciting harmonics are in synchronism with the natural torsional frequency of the shaft system result in large vibration amplitudes and torques. Because each installation has an unlimited number of critical speeds, it is indeed fortunate that only a few of these critical speeds are of dangerous magnitude and also that only a few are in the operating speed range.

Amplitude and Stress Calculations

Another step in vibration analysis requires the determination of the work done on the vibration by the harmonic torque. It was noted above that the engine torque, which goes through a periodic varying cycle each revolution in a two-cycle engine and every two revolutions in a four-cycle engine, is actually composed of a great number of individual harmonic torques. Although each of these harmonic torques "forces" or tries to twist the mass-elastic system at the same time, only that harmonic which synchronizes with one of the natural frequencies can do work upon the twist motion. This may result in a vibration having a large amplitude.

This can be explained by the following definition of work E,

$$E = \int_0^{2\pi} T d\Theta$$

in which T is a harmonically varying torque and Θ is simple harmonic angular motion. The value of this definite integral taken between the limits 0 and 2π results in the following equation for work E during a cycle of vibration:

$$E = \pi T_r \Theta \sin \Phi$$

where

T_r = the exciting torque harmonic for the critical speed being analyzed, expressed in in.-lb. This value must be obtained by a harmonic analysis of the engine turning effort curve.

Θ = the actual angle of twist at the point where the torque harmonic T_r is being applied, expressed in radians.

Φ = the phase angle between the torque T_r and the motion Θ. During resonance the motion always lags the exciting torque by a phase angle of 90° and, therefore, at resonance the work equation for the exciting torque T_r becomes:

$$E = \pi T_r \Theta$$

In multi-cylinder engines, equal exciting torques are applied at all cylinders at definite phase relationship to each other as determined by the firing order. The effect of these phase angles can be entered into the calculation of total work E_T by summing the deflections of each cylinder at its phase angle. Thus the equation becomes:

$$E_T = \pi T_r \Sigma\Theta_{1-n}$$

where

$\Sigma\Theta_{1-n}$ = the vector summation of all the cylinder deflections.

The amplitude of any vibration is limited by the energy dissipated by the damping forces, and it is important, therefore, to estimate the damping energy. At resonance, the energy dissipated by the damping in the torsional system equals the total energy supplied by the harmonic orders of the gas torques. Damping is difficult to evaluate, but seven commonly accepted sources of damping are:

- Elastic hysteresis in the shafting
- Friction of moving parts
- Oil pumping in bearings
- Hydraulic damping of marine propellers and pump rotors
- Clutch slippage
- Magnetic damping of generators
- Air friction.

The amount of energy dissipated in an installation depends upon the summation of all the types of damping in the system. Since damping energy is a function of the torsional amplitudes at the places where damping occurs, the Holzer tabulations, listing deflections (column 4) and change in deflections (column 8), are very helpful in this part of calculation. Thus, by consulting Tables I, II, and III, it can be seen that for the one-noded mode of vibration the majority of the damping is in the armature shaft, for the two-noded mode it is in the engine, and for the three-noded mode it is in the exciter shaft. In this example, the installation appears to use mostly elastic hysteresis damping to absorb the exciting torques.

Most damping equations are empirical. It is necessary to evaluate as much damping as possible so that the total damping energy per cycle can be equated to the total work input per cycle.

However, it is interesting to note that for the one-noded vibration 95 per cent of the total estimated damping is due to the elastic hysteresis in the armature shaft between the flywheel and the armature. This can be seen by glancing at column 8 (Table I), and noting that the change in deflection is much greater in that section of shafting. For this reason, the damping output calculation can be simplified by neglecting the damping in

Node	1	1	1	2	2	2	3
Order	8	12	16	9	12	16	12
RPM	900	600	450	1280	960	720	1240
Estimated Front End Amplitude—Radians	.0034	.00105	.00042	.0026	.0025	.001	.00000015
				VIBRATORY STRESSES—P S I			
Crankpin	1700	530	210	2560	2460	990	0
Armature Shaft	8370	2530	1030	970	930	370	0
Exciter Shaft	1100	340	140	350	330	140	190

Table V—Estimated vibratory stresses in shafting.

all shafts except the armature shaft between the flywheel and the armature. The accuracy still is 95 per cent which is an acceptable figure.

A similar analogy can be made of the two-noded vibration where 95 per cent of the damping energy is absorbed in the engine.

Also, a similar analogy can be made of the three-noded vibration where at least 95 per cent of the damping is absorbed in the armature shaft between the armature and the exciter.

By equating work input for each harmonic to the damping energy, it is possible to solve the amplitude of vibration equation and obtain the estimated amplitude of vibration Θ_F at the first mass for each order (critical speed). The estimated deflection at any mass in the system can then be found by multiplying the relative deflection shown in column 4 by Θ_F.

Thus for

$\Theta_F = \pm 0.0034$ radians for the one-noded eighth order at 899 rpm, Θ_{FW} at the flywheel is 0.0034×0.4916 or 0.0017 radians.

Similarly the estimated torque in any section of shafting is found by multiplying the $\Sigma J\omega^2\Theta$ value from column 8 by Θ_F:

Torque in armature shaft $= 0.0034 \text{ x } 42.2561 \text{ x } 10^6 = \pm 143670$ in.-lb/radians. The torsional vibratory stress in the armature shaft can then be calculated by the normal equation:

$$\text{Stress} = \frac{16\,T}{\pi D^3} = \frac{16 \times 143670}{\pi (4.4375)^3} = \pm 8370 \text{ psi.}$$

Similar calculations can be made to solve all three modes of vibration. Table V shows a tabulation of estimated amplitude and stresses for this installation. Actual torsiograph records taken later showed excellent correlation of front end amplitudes, the elastic curves, and stresses.

Discussion

The Diesel engine discussed in this example is a satisfactory design for its application as a 1,200 rpm, constant speed drive. It is free of critical stresses at the operating speed of the engine. From a torsional vibration standpoint, it is not an ideal engine, however, because of the stresses present at other speeds. If the operating speed of the engine included 900 rpm, the existence of the one-noded, eighth order frequency with its accompanying vibratory stress of 8,370 psi would be sufficient to reject this system. This critical condition is reached only during starting and stopping of the engine, however. Actually, for transient criticals such as this or where other individual applications permit, twice as much stress is allowable beyond that for a continuous operating speed.

The behavior of an engine does not always indicate the presence of critical torsional vibrations. An understanding and application of the fundamentals of torsional vibration, however, predicts the characteristics of the engine, and the designer then can consider methods of improving the critical conditions. Such improvements are not always easy to make.

To illustrate, suppose the requirement were for the system described to be operated over a wide rpm range, rather than at constant speed. Several solutions might suggest themselves to the designer. Increasing or decreasing the flywheel mass would do very little to improve the conditions since it is very close to the node. Increasing the armature shaft diameter would be of little help since any increase within practical limits (up to 5½ in.) would raise the serious one-noded eighth order critical closer to the operating speed of 1,200 rpm, and the stress would reduce only slightly due to the higher torques at the higher frequency. Decreasing the armature shaft diameter also would be an unsatisfactory corrective measure since it would lower the eighth order one-noded closer to the idling speed, and also the very dangerous one-noded fourth order would be brought too close to the operating speed.

An elastic coupling might prove to be a good solution by reducing the one-noded fourth order below the idle speed, but the expensive design of an elastic coupling would have to be justified in the economics of the application of the overall machine. It is difficult, furthermore, to design an elastic coupling to withstand the large torque variations of the fourth order critical speed. A pendulum damper, harmonic balancer, or fluid damper would be good solutions for this problem, but again the expense of these methods for a single unit would be the paramount considerations.

Conclusion

The number of machinery arrangements is unlimited and each presents its own problems. Torsional vibration can be dealt with in every case, however, by application of the basic approach described here. The result is a reduction of failures from this cause, which, to the user of the engine, means time and money.

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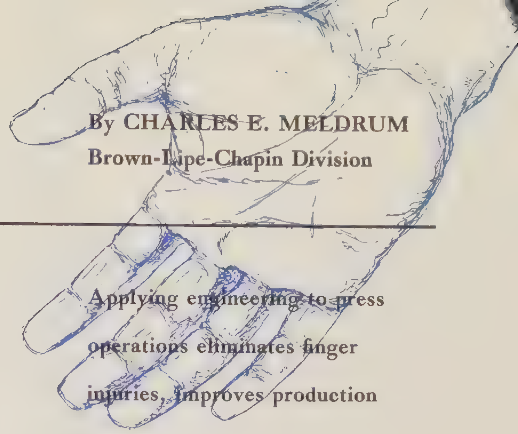
The Elimination of Safety Hazards in Press Operations



By CHARLES E. MELDRUM
Brown-Lipe-Chapin Division

Applying engineering to press operations eliminates finger injuries, improves production

Punch press operations have constantly been studied by the metal working industry to reduce the frequency and severity of hand injuries to workers. Yet in spite of the use of generally accepted safety measures, press plants still experience accidents involving loss of fingers by workers. The Brown-Lipe-Chapin Division's Elyria, Ohio plant cut its accident loss to zero for punch presses by improving the design of safety devices and operating methods.

THE safety hazard of punch press dies clamping shut is a familiar one to plant operators, machinery manufacturers, and safety organizations alike. Elimination of this hazard is frequently sought through such means as two-hand controls, safety pliers, handcuffs, and various types of guards. Usually, however, the design of special safety devices and the sound application of methods engineering are required to solve the safety problems of punch press operations—each of which is likely to be different.

At the Elyria, Ohio plant of the Brown-Lipe-Chapin Division, a study of punch press operations to determine how to eliminate the safety hazards was recently completed. The recommendations of the study were put into effect with gratifying results. During the year 1952, not a single lost-time accident was incurred on a punch press.

The study first determined the location of the hazardous operations and then was devoted to (a) use of mechanical loading and unloading devices, (b) standardization of die design for safety purposes, and (c) safety guard design.

Before describing how the hazards were eliminated, it is appropriate to examine the organization of safety activities at the Elyria plant. The number of employes, including those on multiple-shift operations, is relatively small compared to some of the other GM plants. The type of work performed includes punch press, buffing, grinding, die-casting, plating, and welding, in addition to such regular factory requirements as receiving, shipping, and transporting of materials. The size of parts produced ranges from hood ornaments to front-end grilles for automobiles.

The safety staff includes the safety director, a safety inspector, a physician, and a nurse. Every employe of the plant may, however, find himself involved as an individual in some safety activity at one time or another. First of all, there is the plant suggestion system through which employes may submit safety ideas.

Secondly, specific safety jobs—like eliminating the punch press hazards—involve the specialized knowledge and services of certain employes such as a toolmaker, a maintenance man, and a process engineer.

A third participation in safety by employes—one which is particularly successful at Brown-Lipe-Chapin—is a safety meeting held by three separate groups, each one on a monthly basis. These groups are known as a foremen's group, a utility men's group, and a policy group. A *utility man* in a production department has a number of special duties and his job classification is below that of a foreman. In non-production departments, his counterpart is known as a *leader* and the leaders also attend the utility men's safety meetings.

Members of the management staff are present at the meetings of all three groups making it possible for safety information to flow downward and for suggestions to flow upward. The meetings are held on an informal discussion basis with the result that every man has a chance to talk freely about new safety proposals and about any questions or suggestions coming from his department. Brief minutes of these meetings are kept so that no worthwhile idea is overlooked. A strict follow-up is maintained.

This participation-type meeting, in contrast to a more formal, lecture type, stimulates a greater interest in safety on the part of the factory departments with the result that many new safety ideas are put into effect. Furthermore, the foremen, utility men, and leaders, because of the safety awareness instilled in them at these meetings, are able to perform, in effect, the function of a safety inspector for their own departments.

Hazardous Operations

In initiating the study of punch press hazards at Brown-Lipe-Chapin, it was recognized that to prevent accidents involving the loss of fingers or thumbs, press operations must be performed in such a way that it is neither necessary nor possible for operators to get parts of their bodies between pinch point areas in punch press dies. The operations were examined, therefore, to determine the feasibility of using mechanical loading and unloading devices.

The first step in eliminating safety hazards is to recognize where the hazards exist. This was accomplished at Brown-Lipe-Chapin by means of a *safety check sheet*, which was developed and used to facilitate locating the hazardous operations. The histories of all lost-time press operations were reviewed to determine the cause for each accident that occurred. The information obtained from this source was used to develop the questions on the check sheet. The questions directed attention to one phase of a press operation at a time. The answers indicated whether or not a hazard which previously caused a lost-time accident still existed on the same or another operation.

The most common causes of accidents which previously occurred in the punch press department are listed below:

(a) Placing hands in "pinch point" areas
(b) Improper placing of hands
(c) Using hands instead of clamps
(d) Placing pieces improperly

Press Operation Check Sheet for Safety

1. Type of press (C-frame) (toggle action) (horning and wiring) (straight-side) (other)
2. Type of clutch (mechanical) (air)
3. Speed of press
4. Type of material used on operation (sheet) (coil) (parts in process) (blanks) (other)
5. Size of material
6. How is material brought to operation?
7. How is material stored at place of operation?
8. How is material fed? (pliers) (suction cup) (special tool) (mechanical, air or hand slide) (gravity slide) (automatic) (other)
9. Does any part of operator's body enter the danger zone while loading or unloading? (yes) (no) If yes—what part? ( )
10. How is the press put into operation? (foot) (one hand) (two hands) (other)
11. If press is two hand control, must operator hold both buttons until die is closed? (yes) (no)
12. How is part removed from die? (air) (mechanical) (hand-using tool)
13. How is trim or offal disposed of? (mechanical) (air) (hand-using tool)
14. Where is completed piece placed? (chute or conveyor) (table) (tub or container) (stacked on floor) (other)
15. Do you feel operation is safe?
16. If answer to 15 is NO—explain
17. What suggestions do you have for improvement?

Location of Press____________
Checker____________
Date____________
Department____________

Table I—The safety check sheet reveals to anyone the existence of safety hazards on a press operation. It is used by the foreman, the safety inspector, and the process engineer.

(e) Fastening down one button of a two-hand control

(f) Handling and turning dies over on die tables or on the floor

(g) Insufficient operator training or follow-up by supervision

(h) Using hands or fingers instead of safety pliers or other equipment provided

(i) Two or more persons operating a press

(j) Failing to keep safety guards or equipment in repair

(k) Failing to keep work area clean

(l) Failing to concentrate on operation while performing same

(m) Mechanical failure of press.

Table I gives the information contained on the safety check sheet. Experience with these check sheets has shown that they should be used not only by the foreman in charge of the operation, but also by the safety inspector and a member of the process or tool engineering department.

The foreman in charge should use the check sheets because he is the one member of management who is closest to the particular operation involved.

The safety inspector should use the check sheet because he is the one person who will look at all phases of the operation from a safety viewpoint only.

The tool engineer or process man should use the check sheets because either of them may have knowledge of how to overcome difficulties which neither the foreman nor the safety inspector are able to solve.

Feasibility of Use of Mechanical Loading and Unloading Devices

Mechanical loading and unloading of punch presses is advantageous from both an efficiency and a safety viewpoint. For efficiency, the punch presses can be set to run at their maximum strokes per minute without having to stop while an operator takes out one piece and inserts another. For safety, the device is performing the operation; therefore, the operator is not exposed to danger.

Costs of mechanical loading devices vary widely due to differences in the service performed. Some devices may consist of only a few relatively simple sheet metal parts; others may be fairly complex and cost several thousand dollars. The examples described in this paper indicate, however, that the equipment soon pays for itself through eliminating the possibility of accidents. In some cases the improved efficiency, resulting from a safety device, is a byproduct which also contributes to the overall saving. Most important, however, is the tremendous value of protection to workers against hand injuries, for only the safe job is a good job.

The various types of mechanical loading and unloading devices which are in the Brown-Lipe-Chapin Elyria plant are as follows:

- Hand operated slide feeds
- Gravity type slide feeds
- Power operated slide feeds
- Magazine type feeds
- Automatic coil feed
- Iron hands
- Conveyor feed and automatic removal.

Each device is used first because it has proven to be safe. Another consideration is adaptability to a specific application.

Hand Operated Slide Feeds

The hand operated slide feed is one in which the part is loaded outside the danger zone and then pushed by hand taking the part to the point of operation.

An example of this type feed is applied to the draw operation for a radiator grille moulding. Before the feed was installed, the die was put into production with a cage type guard and the following operating method was used:

(a) Pick up blank and insert into pliers

(b) Insert blank into die with pliers

(c) Remove pliers and step on foot pedal to operate press. Upon completion of the press cycle, the part was blown off the die and into a chute which guided it to the next operation.

A hand operated slide feed was attached to this die and the operating method changed to the following:

(a) Place blank on slide with left hand and push slide to stop

(b) Pull slide back to start position and step on foot pedal.

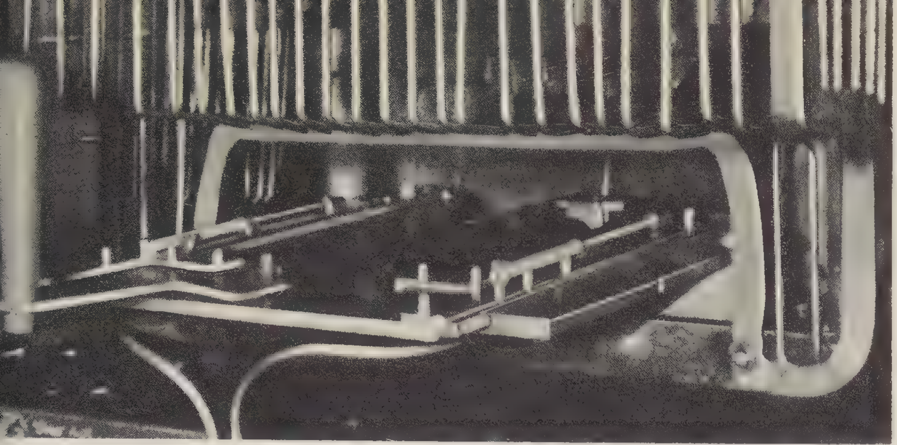


Fig. 1—Blanks are located on the die by this hand slide feed. The operator's left hand guides the handle of slide while the right hand presses the control button located out of the picture. A front cage guard with its opening sufficient only for the slide clearance also is illustrated. Workers hands cannot pass through the opening, eliminating the safety hazard.

Safety was improved because the opening in the cage type guard could be decreased to the thickness of the slide. This made the opening smaller than that necessary in the former guard for opening the pliers to release a blank. The result was an effective restriction to a worker's hand entering the die area.

Production was increased because several blanks could be held in the operator's hand preparatory to placing them directly into the feeder; whereas, with the use of pliers, only one blank could be handled. Furthermore, the feeder located the blank automatically against locators on the die. With the pliers it was necessary for the operator to position the blank against the locator.

The very low cost of building and installing this guard made the investment well warranted. A typical hand slide feed is shown in Fig. 1.

Gravity Type Slide Feeds

The gravity type slide feed is a simpler and cheaper device than hand or power operated slide feeds. Attached directly to a die, it guides the parts themselves into the die. The slide is shaped to hold parts in the proper location for their entry into the die, and its application is limited to parts of such shape that they will slide easily and locate themselves in a die. In addition to the chute type, gravity slide feeds are sometimes made of rollers as in a gravity roller conveyor.

In this paper, slides on which the operator pushes one part with another part are considered gravity slide feeds.

The gravity slide feed is safest if used in conjunction with a cage type guard which has an opening large enough for the part but not large enough for fingers. If the opening must be large, the operation can still be safe if the operator has to be at arm's length away from the danger zone to operate the press.

A typical use of the gravity type slide feed is on an operation for forming bumper-guard anchor plates. Previous to the addition of the slide, the operator inserted each blank with a pair of pliers. The operator now slides the blanks through the small opening in the cage. In addition to greater safety, an easier and faster method of feeding this press resulted from the use of the slide.

Power Operated Slide Feeds

Power operated slide feeds using air have been installed on bumper-guard trim presses for several years at Brown-Lipe-Chapin and have proved to be 100 per cent safe. Previous to their use, operator protection was provided by a sweep guard used in conjunction with a cage guard. The operator was required to place the bumper guard on the horn of the die and then pull a clamp into position which held the part while he stepped on a foot pedal to operate the press.

With the power operated slide feed as shown in Fig. 2, the operator places the part on a nest which holds the part in proper position for entry into the die. He then must use both hands to press the slide operating buttons. The buttons operate an air cylinder which pushes the part onto the die. The punch press cycle is started by switches which are located so that the slide depresses them when the part is properly located on the die. If the operator removes either hand from a slide operating button before the press operating switches are depressed, the slide will return to its starting position and the press will not cycle.

After the press ram has gone past bottom center, the operator removes his hands from the buttons and the slide returns with the completed part. The offal is blown out of the rear of the die onto a chute, finally dropping into a scrap bin.

Magazine Type Feeds

The magazine type feed gets its name from the fact that several parts are stacked into a specially designed holder and mechanically fed into the punch press from the holder.

This type feed is excellent from a safety point of view as there is no necessity for an operator to place any part of his body between dies. It also has advantages from a production viewpoint because the feeder can be synchronized to work with the speed of the punch press.

Another good feature is that the magazine can be made large enough to hold a definite number of parts which will keep the press busy for a specific length of time. During the time the magazine is unloading, the operator may be kept busy on a similar operation or some other duty.

A typical use of the magazine type feeder is on a press operation for an automobile hub cap body. The feeder, which is attached to the front of a Bliss No. 28 punch press, is loaded with flat, 11-in. diameter blanks of 0.028 in. cold rolled steel. As the starting lever is depressed, the feeder slide advances and deposits one blank in position on the die. When the feeder retracts and is clear of the die, it engages the press operating lever which causes the press to make one cycle. At the end of the press cycle, the completed part is ejected by air through an electric-eye beam. When the beam is broken, the entire operation is repeated.

To prevent die breakage due to two blanks being fed at one time, the thickness of the feeder slot, through which the blanks pass, is held to a dimension less than the thickness of two blanks. Satisfactory performance of this feeder also requires that the blanks be flat, free of burrs, and have constant thickness.

About 1,000 blanks at a time, enough for a one-hour run, are loaded on this feeder. To compensate for the decrease in weight of the feeder as the blanks are used up, a constant pressure is applied to the stack of blanks by means of an air cylinder.

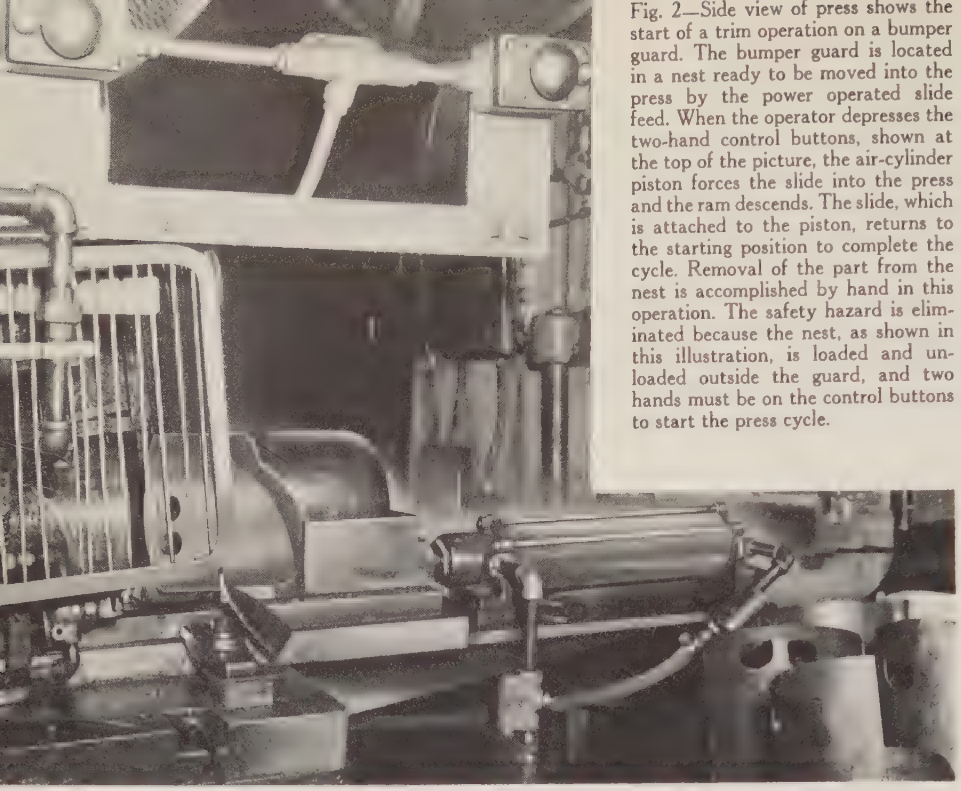


Fig. 2—Side view of press shows the start of a trim operation on a bumper guard. The bumper guard is located in a nest ready to be moved into the press by the power operated slide feed. When the operator depresses the two-hand control buttons, shown at the top of the picture, the air-cylinder piston forces the slide into the press and the ram descends. The slide, which is attached to the piston, returns to the starting position to complete the cycle. Removal of the part from the nest is accomplished by hand in this operation. The safety hazard is eliminated because the nest, as shown in this illustration, is loaded and unloaded outside the guard, and two hands must be on the control buttons to start the press cycle.

Automatic Coil Feed

Automatic coil feed, as the name implies, feeds stock to a press from a coil instead of in short strip lengths. Two types of commercially-available coil feed machines are used at the Elyria plant. The type illustrated in Fig. 3 is used in conjunction with blanking operations for bumper-guard blanks, and also with blanking and forming operations on anchor plates.

Previous to installation of the coil feed equipment, these operations required the purchase of stock in lengths about ten feet long so that the stock could be handled by the operators. After the coil feed equipment was installed, the slower, more difficult method of hand feeding was eliminated.

A good example of the savings which can be made with automatic coil feeding may be seen from an application to a blanking operation for automobile bumper-guard anchor plates. The following equipment was purchased:

1—coil feed machine for 0.150 in. thickness, 10 in. width by 11 in. advance (machine capacity: 0.187 in. thickness, 5½ in. width).

1—coil cradle and straightener for 12 in. width by 48 in. outside diameter coil.

Savings were realized in (a) material, due to buying coil stock instead of strip stock, and (b) in labor cost.

A second type of coil feed is used in conjunction with presses and dies to produce stainless cap mouldings and steel inner bars for front-end grilles.

In the case of the stainless cap moulding, the die is designed to blank and form the piece. The formed piece is blown from the die against a limit switch and then drops to a conveyor belt. The action of the piece against the limit switch causes the press and feeder to repeat their operations, and thus make the operation automatic and continuous at the press-strokes-per-hour rate of 2,000. If a piece does not come out and hit the limit switch, the operation will stop until the cause for failure has been corrected and the press started again.

The safety of the automatic coil feed is apparent from the fact that cage type guards completely enclose the die, and further that no operator is needed except for reloading the feeder.

Stock used in the above operation is 0.018 in. by 10½ in. wide. The coil weight is 4,000 lb.

In the case of the inner bar, the operation is the same but the material is cold rolled steel, 0.031 in. by 11$\frac{1}{16}$ in. The coils weigh up to 6,000 lb.

Iron Hands

The iron hand for removing parts from punch presses was introduced to industry only a few years ago, but it is gaining steadily in popularity and use. It was originally designed for use on large parts such as automobile roof panels and fenders, but is now used in many plants on a variety of comparatively smaller, but awkward-to-handle parts.

Although some plants manufacture their own version of the iron hand, it can be purchased from a commercial source. Three sizes are offered for mounting on a punch press. These handle stampings ranging in weight from 20 lb to more than 100 lb at speeds of from 20 to 30 pieces per min.

Also available is a new, portable type automatic unloader capable of removing parts at the rate of 35 per min.

In operation, the iron hand moves into the die and grips the part at the moment the ram rises sufficiently to permit removal of the part. It lifts the part out of the die and swings back, placing the part on a table or conveyor. The iron hand then returns to its original position awaiting the next part.

The following study at Brown-Lipe-Chapin resulted in the decision to install three iron hands on a press line for bumper guards.

The press operations (which remained unchanged as a result of the use of iron hands) are performed in the following order:

(a) Draw—300-ton toggle type press

(b) Brehm trim—290-ton single action press

(c) Cut-apart—75-ton press.

In the draw operation, the operator uses pliers to place an oblong shaped blank, 0.072 in. thick by 12½ in. by 24½ in. onto the draw die. He then depresses two press operating buttons which he must hold until the die is completely closed. When the press cycle is complete, the operator removes the piece with pliers and places it on a table to his left.

As a safety measure, the operator is not allowed to remove the piece until the press ram and blank holder movement have come to a complete stop. This safety precaution is taken to protect the operator in case of electrical or mechanical failure which would allow the press to repeat.

Use of an iron hand improves safety by eliminating any need for movements in and out of the die by the worker. The iron hand also eliminates the time allowed for the operator to remove parts since the iron hand can move in and remove the piece as soon as the press begins to open. Saving the time allowed for an operator to remove the piece, in this example, results in an increase in hourly production on the draw operation.

In the Brehm trim operation, the same amount of time is saved and a similar increase per hour made. The important safety feature in both instances is that the operator's hands (with pliers) are not being used for parts removal.

A comparison of the two methods showed that in achieving this improved safety, the expected increase in production and the reduction in overall manufacturing cost for these operations would pay for the equipment.

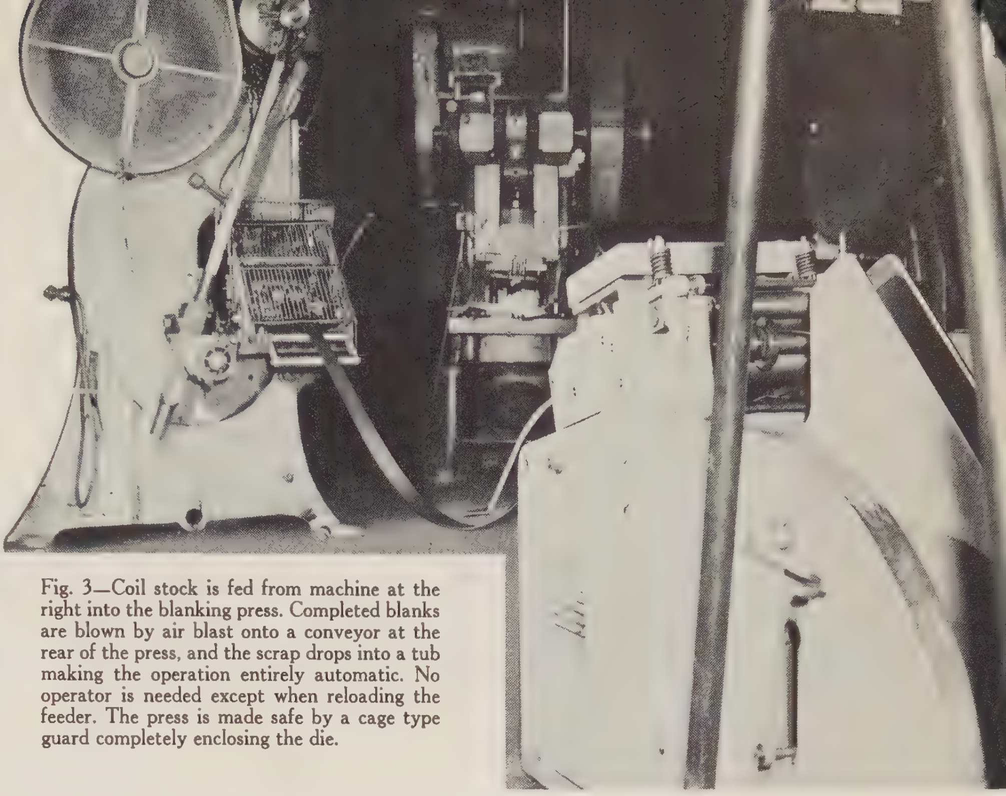


Fig. 3—Coil stock is fed from machine at the right into the blanking press. Completed blanks are blown by air blast onto a conveyor at the rear of the press, and the scrap drops into a tub making the operation entirely automatic. No operator is needed except when reloading the feeder. The press is made safe by a cage type guard completely enclosing the die.

Conveyor Feed and Automatic Removal

A method of feeding parts into a punch press from a belt conveyor was recently adopted on a clinching operation for a hub cap assembly as illustrated in Fig. 4. To make the operation completely automatic, removal from the press is accomplished by means of an air-operated piston with hook attached. This device is attached to the front of the punch press, and is operated by a limit switch and solenoid valve. The result of this installation was a further improvement in safety due to automatic operation.

Previous to the addition of automatic equipment, the sequence of operations was as follows:

Operator No. 1

(a) Remove hub cap body from bin
(b) Remove hub cap cover from conveyor line
(c) Place cover over body and put assembly back on conveyor line

Operator No. 2

(a) Remove cover and body from conveyor line and place on gravity slide feed
(b) Remove completed assembly from punch press and place on conveyor line.

The punch press in this case was equipped with an electric-eye which caused the press to operate when a part slid down the gravity chute and into the die.

With the addition of automatic equipment to this operation, the sequence becomes:

(a) Remove hub cap body from bin
(b) Remove hub cap cover from conveyor line
(c) Place cover over body and place assembly on inclined belt conveyor feeding punch press.

The operation, from this point forward, is automatic.

The cover and body assembly drops from the inclined belt conveyor onto a gravity chute which guides the assembly into location on the clinch die. Upon reaching the proper location on the clinch die, the assembly breaks the electric-eye beam which causes the punch press to operate.

After the clinch operation is completed, a cam on the crankshaft of the punch press trips a limit switch which controls the air-operated removal device. The hook at the end of the rod on the air cylinder pulls the completed hub cap assembly out of the die and onto another gravity chute. In sliding down this chute, the hub cap assembly passes over another limit switch before dropping onto a conveyor line which takes the hub cap assembly to the packers. The press will not begin a new cycle until this limit switch has been tripped by an outgoing completed assembly, the purpose being to protect the die against damage due to "doubles." Even though the previous method of operation had caused no accidents, the adoption of the automatic method described above resulted in still further improvement in safety with no loss in production rate.

Standardization of Die Design for Safety Purposes

Many safety features can be included in the design of dies for punch presses. Typical examples are scrap cutters, guide post guards, kickers, drop-through dies, and pick-offs.

Scrap Cutters

In blanking operations and in large trim operations, there is metal left that is no longer a part of the piece being manufactured. The metal that is left has sharp edges or prongs which can cause serious lacerations to an operator. To make this metal safer to handle, it is usually cut into small pieces.

In blanking operations where a *skeleton* is coming out of the die, scrap cutters can be attached to the outgoing end of the die. The scrap cutters act as shears, and, with each stroke of the press, they cut off whatever metal comes out of the die. The scrap that is cut off is

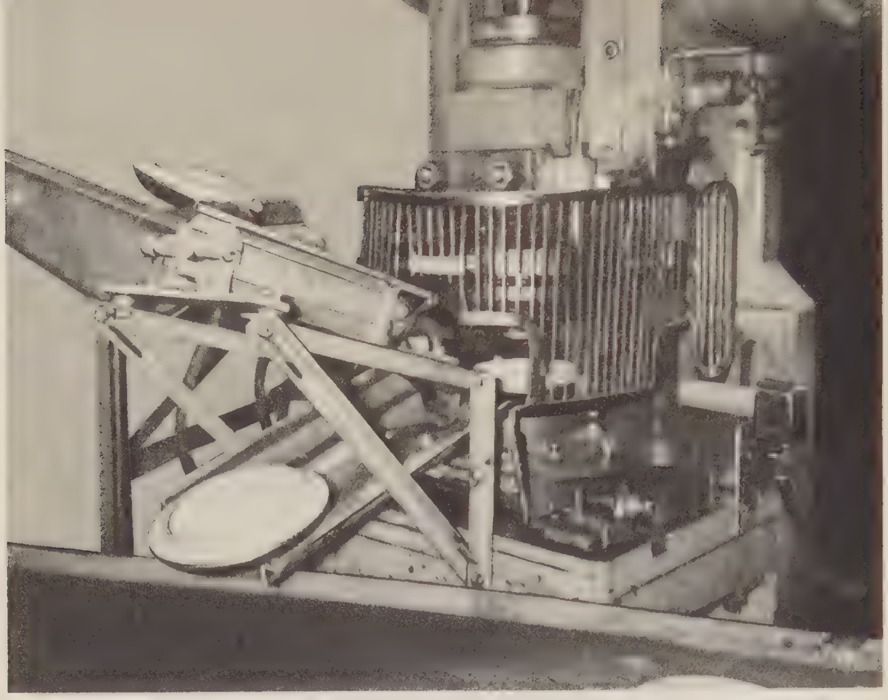


Fig. 4—Hub caps are fed into this press from the top of the inclined belt conveyor, shown at the upper left. As the hub cap drops into the die, the beam of an electric-eye control, shown at the right, is broken causing the press to operate. As the ram moves upward, a cam mechanism actuates the air-operated hook which pulls the hub cap onto the gravity ejection chute. The limit switch—located in the center of this chute—must be tripped to permit a new cycle to start. No operator is required at this location. A cage type guard provides added safety to other workers in the area.

directed into a scrap tub or onto a scrap conveyor. In this way, it is not necessary for the operator to handle the scrap.

Guide Post Guards

Most dies require guide posts and bushings. The guide posts are mounted on one half of the die, and they enter bushings located in the other half of the die as the ram descends. When the press is in the open position, the guide post is out of the guide post bushing. This situation presents the danger of an injury should an operator place his hand over either the guide post or the guide post bushing when the die closes.

One method of safeguarding this hazard is to use guide post guards as shown in Fig. 5. Another method uses guide post extensions so that the guide post does not come out of the guide post bushing. The types of guide post guards include telescoping and spring type guards.

Kickers

A recent development of the Fisher Body Division, General Motors Corporation, is a gadget known as a *kicker*. The kicker, or parts ejector, is merely an air cylinder which locates on or in the die. It is actuated by the up-stroke of the press and kicks the completed part from the die.

Drop-Through Dies

Drop-through dies for blanking operations are particularly advantageous for easy and safe parts removal Since the blank drops straight through the die, a conveyor, chute, or stacker is easily adapted to the operation.

Pick-offs

When a formed part remains on the die, an operator might place his hands in danger trying to remove the part from the die. If a pick-off is designed for the die, this hazard is eliminated. The pick-off is nothing more than a hook attached to the top half of the die. The hook pulls the completed part off of the die as the ram rises to the top of the press stroke.

Safety Guard Design

The majority of punch presses in use at the Brown-Lipe-Chapin Division are small, short stroke, mechanical clutch type presses. Accident reports have shown that this type of press causes the majority of accidents involving amputations. Much work has been done, consequently, on developing guards to fit various dies and presses. These guards are commonly called *cage type* safety guards, or point-of-operation guards.

The main purpose of a cage type guard is to completely enclose the die, leaving an opening sufficient for entry of parts to be processed. Complete success is attained when the opening can be smaller than that necessary for a person's finger.

The three general types of cage guards are known as side guards, front guards, and complete, or tailor-made, guards.

Side Guards

The side guard is attached to a punch press and becomes a part of the press. The side guard consists of a left-hand and a right-hand unit, and each unit is made adjustable in order to attach it by means of a hook to the front grille guard.

The frame of the side guard is made of ⅛ in. by 1 in. cold rolled steel. The grille bars, or rods, are ¼ in. diameter cold rolled steel and are spot welded to the frame. The rods are spaced 1¼ in. apart.

The overall sizes of these guards vary with the size press on which they are being used. Side guards must be long enough to cover the opening between the back of the press and the front of the bolster plate, and they must be wide enough to cover the side completely when the press ram is at its top position.

Front Guards

The front grille guards are made of the same material as the side guards. They differ in design in that they have an opening for entry of the parts to be processed. In general, the front grille guard must be made to suit the press as well as the die. For that reason, the front grille guard measurements are taken when the die is set up in the proper punch press ready for production. The guard is bolted to the front of the die.

The most important safety consideration in the application of the front grille guard is that the opening be no larger than absolutely necessary for entry of the part, and that the opening be placed in the best location for easy and safe operation.

Tailor-Made Guard

This type of guard is one which completely guards a specific die. It is made of the same materials as the front and side guards.

Conclusion

Eliminating safety hazards in press operations is accomplished not by safety gadgets and guards alone. These are important tools, but with them there must be a study of the press loading and unloading operations, and there must be an effective safety organization among all of the employes. An approach from these three points offers the opportunity for the highest degree of safety for workers in press plants. An engineering analysis of the method of doing work may suggest a better way, and very often the better way is the safer way. In addition to providing safer operations, some of the safety improvements enable a department to show higher production rates and lower costs than formerly.

In small plants, personnel such as a process engineer and a toolmaker are assigned to carry out many special safety assignments.

An indirect effect of adopting new safety improvements is the increased awareness of safety by employes. Without the interest and cooperation of supervisors and employes, no safety program is successful.

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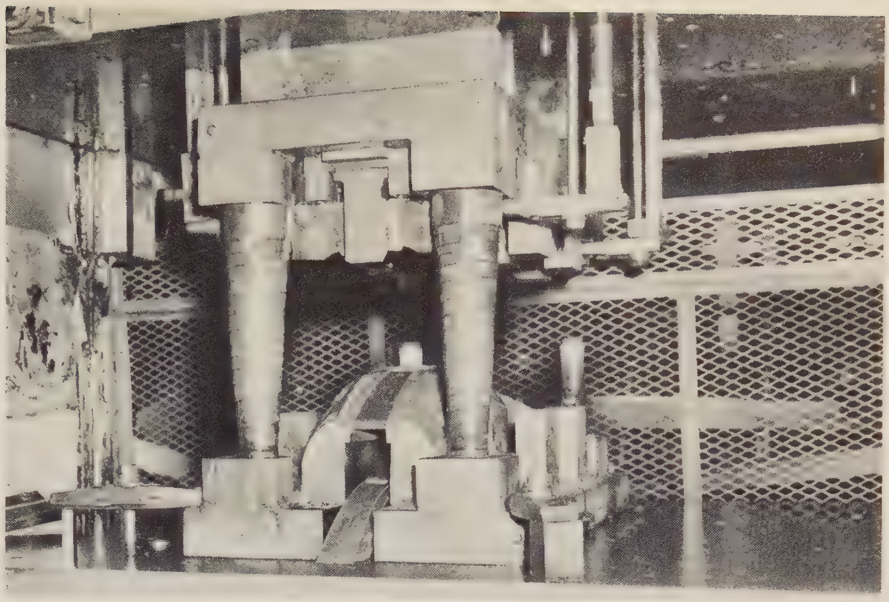


Fig. 5—Telescoping coil of metal protects against injury from guide posts. This illustration shows two guide posts at the extreme rear of the die. On this press these rear guide posts are beyond the reach of the operator and therefore do not require special guards. A conventional grille across the rear of the machine makes it safe for other workers in the general area.

Glossary

For paper beginning on page 15: "The Elimination of Safety Hazards in Press Operations."

Piercing is the operation of cutting openings, such as holes and slots, in sheet material, plate, or parts.

Blanking is the shearing or cutting of outside contours or shapes, called blanks, out of sheet or strip stock.

Bending is a press operation in which the punch pushes the stock into cavities or depressions of corresponding shape in the die.

Forming is the process of changing the shape of a sheet metal blank by applying pressure on the blank when it is placed between a punch and a die.

Trimming is a secondary cutting or shearing operation on previously formed or drawn parts in which the surplus metal is sheared off to the desired shape and size.

A **ram** is the main reciprocating member of a press to which the punch (or die) is attached.

A **nest** is a plate, with an opening to conform to the contour of a given part, fastened to the top of a die block. It acts as a locator for the part in secondary operations, such as piercing, forming, and trimming.

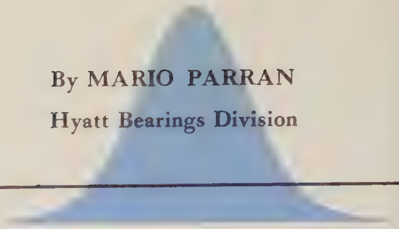
Pressing is the action of the ram forcing the die to close with a sheet metal blank between the top and bottom half of the die.

A **bolster plate** is a plate secured to the top of the bed of the press onto which the die is fastened.

A **horn** is a cantilever block or post which acts as the die, or to which the die is fastened in the case of a straight-front press.

Brehm trim is the trade name for a "shimmy die." It is a cam trimming die for square-edge triming of shells or parts at right angle to the wall of the shell.

Mathematics Necessary for Quality Control in Mass Production



By MARIO PARRAN
Hyatt Bearings Division

Industry applies the statisticians' tools to make a better product

The day is fast disappearing when an industrial organization, burdened with product quality problems, progresses and competes with other manufacturers without the use of statistical methods of quality control. The recent wide application of statistical methods to mass production makes possible the optimum use of raw materials and machines, increases economy in production, and raises the standards of the manufactured goods to a new high. This application of mathematics in industry opens still another field where a knowledge of mathematics is valued.

INDUSTRY has used statistical quality control in some form for more than twenty years. Yet, it has been only within the last several years that the use of the term *quality controlled* has made the public aware of the role of quality control in the manufacture of foodstuffs, textiles, and other consumer goods.

Manufacturers always have controlled their quality; otherwise they could not have stayed in business. If the consumer buys his favorite brand of canned peaches today he expects the same quality next month when he again buys that brand; otherwise he will probably switch brands.

Not until recently, however, has the use of *statistical methods* been adopted by manufacturers to improve still further their control over quality of products. Such methods, meanwhile, have proven to be more reliable and more economical than the methods previously used. By means of statistical methods, it is possible to reduce variability in products to a minimum, and, as a consequence, to enjoy an expanding market of satisfied customers.

Whatever article a manufacturer produces, it must be produced to a certain degree of quality, and it must be competitive in price with similar products on the market. The quality of products must remain stable. The manufacturer's ability to produce consistently to a specified standard determines his ability to produce a quality product.

Quality Control Defined

Today, the term *quality control* means statistical quality control. The word statistical is usually dropped, however, partly because it is difficult to pronounce, and partly because the word is full of mystery for most people. Quality control can be described as the science of preventing defects and maintaining the uniformity of a product through the use of statistical methods. Its earliest applications were on acceptance sampling of bulk materials, such as coal and munitions, that can be evaluated only by destructive tests.

During the late twenties and the thirties, the use of quality control spread slowly. It was not until World War II when it was imperative to manufacture war materiel to a high degree of precision with low loss in scrap, and to reduce inspection effort to a minimum, that quality control was given great impetus by the armed forces. It was this wartime effort that placed quality control in the fore.

The two pioneers in quality control were E. S. Pearson in Great Britain, and Walter A. Shewhart in the United States. They took the basic concepts of variation, which up to that time had been used only in theoretical statistics, and developed the control chart as a practical shop tool for controlling quality. Shewhart's book, *Economic Control of Quality of Manufactured Product*, was probably the greatest single factor in the development of quality control.

Role of Quality Control in Manufacturing Firms

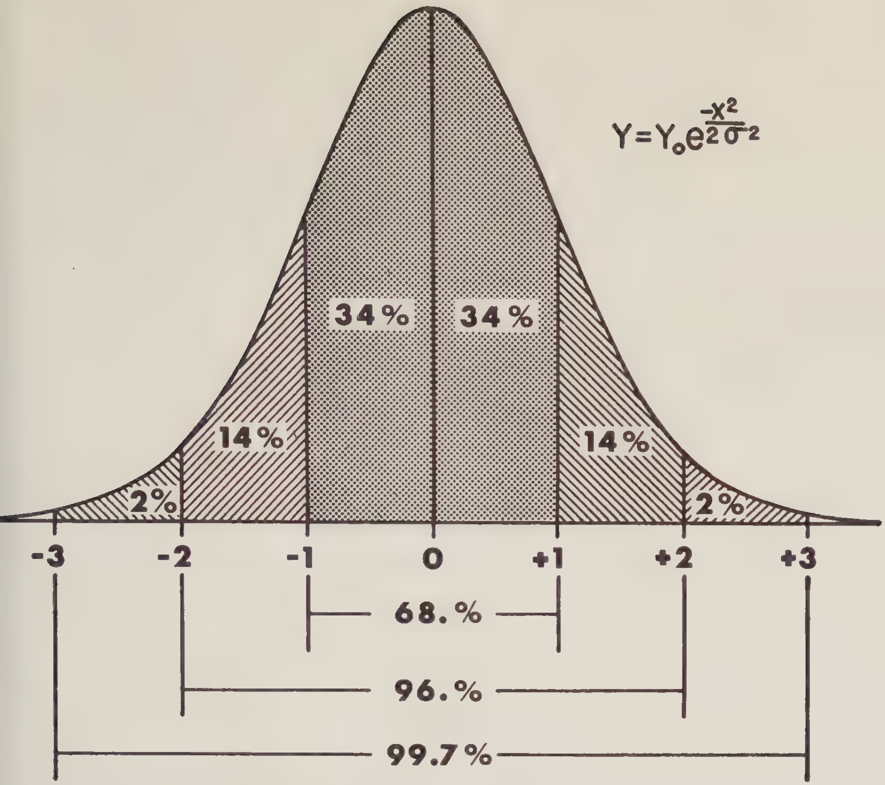
In most modern manufacturing concerns, a staff member, known as the director of quality control, is given responsibility for maintaining quality and preventing defects. He usually acts in the capacity of consultant to the inspection, manufacturing, and sales departments on matters of quality. He has a staff of technicians under him who not only have been trained in the principles of statistics, but also understand manufacturing and inspection methods. A typical organization chart of the quality function is shown in Table I.

Acceptance Function

Quality control in a well organized concern does not take over any of the three functions listed in Table I—as many are led to believe. Instead, it

INSPECTION (Acceptance Function)	QUALITY CONTROL (Preventive Function)	QUALITY ASSURANCE (Assurance Function)
Receiving Inspection	Economic Studies	Customer Complaints
Process Inspection	Process Capability Studies	Quality Audit
Finished Goods Inspection	Design of Experiments	Check Inspection
Gauge Maintenance	Design of Sampling Plans	Market Quality Determination
Test Equipment Maintenance	Analysis of Data	Accuracy of Inspectors
Salvage	Statistical Methods	Executive Reports on Quality
Day-to-day Trouble Shooting	Training in Quality Control	

Table I—Organization chart of the role of quality control in a manufacturing firm showing the three functions of quality control.



ig. 1—The Shewhart control chart is based on the tatistical law that no two things are alike but ary according to a definite pattern. If a large ample of parts with a controlled variable, for xample bearing diameters, are arranged in a requency distribution, the diameters tend to luster about a mean and 99.7 per cent of the parts ill be within plus and minus three standard eviations (or three-sigma) from this mean. This istribution will approximate what is called a ormal, Gaussian, or bell-shaped curve. Any point n the ordinate is obtained by the formula: $= Y_o e^{\frac{-x^2}{2\sigma^2}}$ where Y_o is the maximum value of ; e is the base of the system of natural logarithms .7182818205); σ^2 is variance.

orrelates them. In the *acceptance function*, hrough its trained technicians, quality ontrol applies statistical techniques to xisting methods, usually in the form of ontrol charts. By application of these echniques to receiving, in-process, and nished goods inspection, it is possible o produce at lower cost and with less ariation in the product.

reventive Function

The most important function of quality ontrol is the *preventive function* which is oncerned with the prevention of deects. The major parts of this function re: (a) the study of operations or procsses to determine if they are capable of roducing to specification; (b) design of xperiments with statistical methods for reater reliability of results, and (c) esign of sampling plans to effect the nost economical inspection with the maximum of assurance. It is in this preventive function that quality control pays for itself in savings through reduction in scrap and reduced inspection costs by sampling.

Assurance Function

The *assurance function* usually involves investigation of customer complaints and preparation of executive reports on quality. This function generally brings quality control into the realm of sales and management. Actually, it is a management tool. Quality control methods are so far-reaching, and of such importance for economical management, that the quality control department can operate most successfully only if it is a part of management—and it receives this consideration in firms that have applied quality control successfully.

Shewhart Control Chart

The role of quality control in mass production has been described; it is pertinent now to examine the most important tool of quality control in mass production, namely, *the average and range chart, or control chart,* developed by Shewhart. The Shewhart control chart is based on the statistical law that no two things are alike, but vary according to a definite pattern. When a large sample of parts with a controlled variable, such as the diameter of a roller that has been ground on an automatic grinding machine, are arranged in a frequency distribution, the diameters will tend to cluster about a mean, and 99.7 per cent of the parts will be within plus and minus three standard deviations from the mean. Such a distribution will approximate what is called a normal, Gaussian, or bell-shaped curve as shown in Fig. 1.

This technique of forming a distribution is extremely useful for analysis of the lot as to the probable spread of individual measurements, the average value, mode, and other characteristics. It does not, however, show a time trend.

The control chart, as developed by Shewhart, builds a frequency distribution on a time trend basis, with the ordinate as the variable being measured, and the abcissa as time (Fig. 2). Five observations of a sample are usually taken, and the average and range plotted. After a minimum of 25 samples have been taken, at uniform time intervals, control limits can be drawn for averages and ranges within which the points must fall if the process is in statistical control. A point outside of these limits indicates that an assignable cause of variation exists, and should be investigated. The cause may be due to either man, machine, or material.

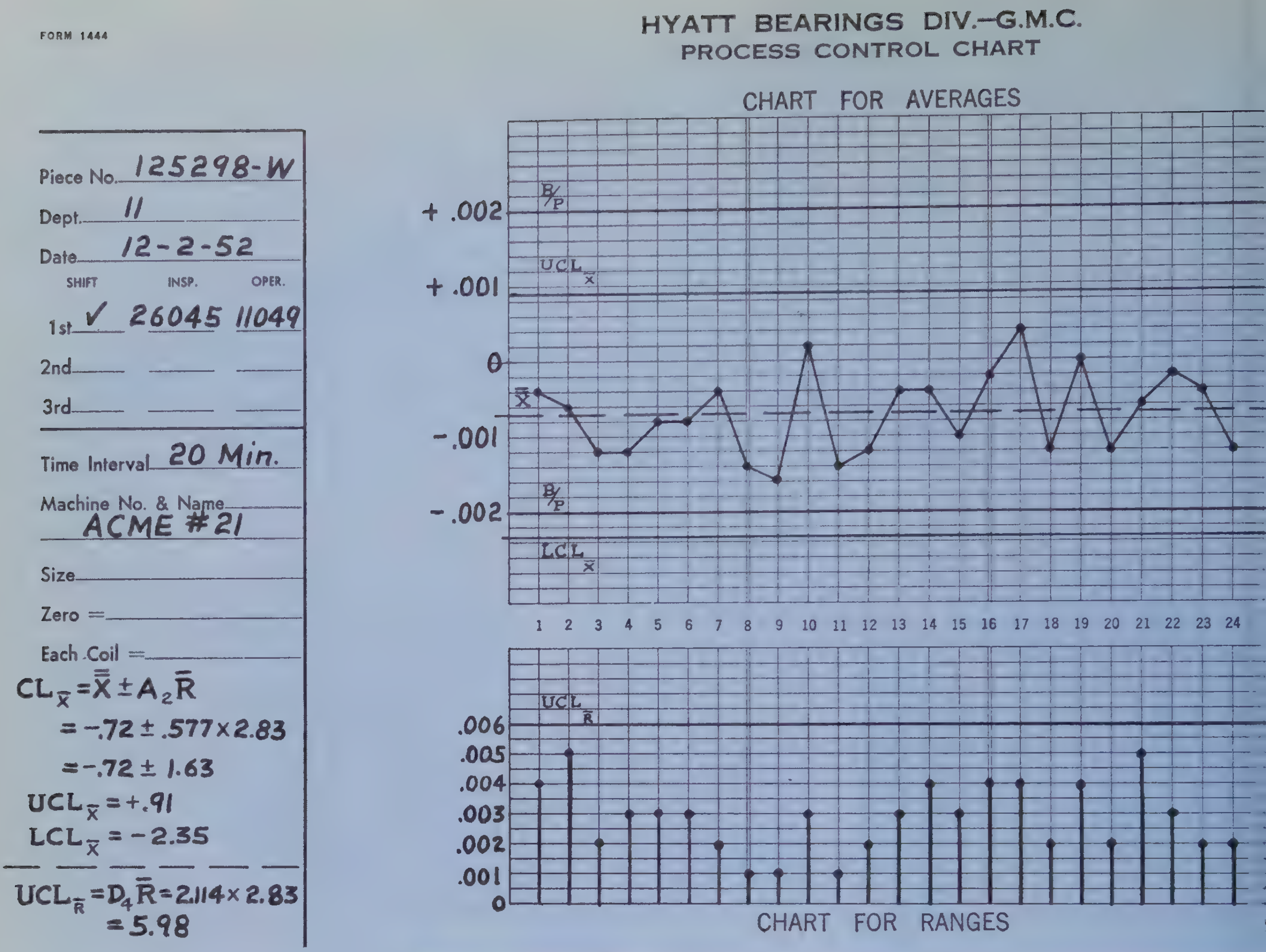
In actual practice, control charts for averages and ranges have three uses: (a) to determine when to search for assignable causes of variation and take corrective action, (b) as a basis to change production procedures, and (c) to determine machine or process capability. In general, a control chart is a record of the past and present achievement and is an indicator of future performance. It is extremely good factual proof to present when arguing a point related to quality.

Mathematics Required in Quality Control

Having this general background of quality control in mass production, the question may now be asked, "What are the mathematical principles that must be understood to apply quality control in industry?" In general, there are three levels of mathematics required in the quality control function:

(a) Simple arithmetic on the inspection line

(b) High school mathematics for the technicians, including advanced algebra, plane and solid geome-


FORM 1444

HYATT BEARINGS DIV.—G.M.C.
PROCESS CONTROL CHART

Piece No. 125298-W
Dept. 11
Date 12-2-52

SHIFT	INSP.	OPER.
1st ✓	26045	11049
2nd		
3rd		

Time Interval 20 Min.
Machine No. & Name ACME #21
Size
Zero =
Each Coil =

$CL_{\bar{X}} = \bar{\bar{X}} \pm A_2\bar{R}$
$= -.72 \pm .577 \times 2.83$
$= -.72 \pm 1.63$
$UCL_{\bar{X}} = +.91$
$LCL_{\bar{X}} = -2.35$

$UCL_{\bar{R}} = D_4\bar{R} = 2.114 \times 2.83$
$= 5.98$

Fig. 2—This particular chart was used in testing machine capability. The control chart for averages and ranges is used to determine where to search for assignable causes of variation. The average and range of five observations of a sample are plotted. Next, a minimum of 25 samples is taken at regular intervals, as shown in the chart on the right hand side, and control limits are drawn for averages and ranges using the formulae in the lower left hand corner. All the points must fall within the control limits if the process is in statistical control. $CL_{\bar{X}}$ refers to the control limit of the average of each group of observations; $UCL_{\bar{X}}$ refers to the upper control limit; $LCL_{\bar{X}}$ refers to the lower control limit. Any point outside these control limits must be investigated. In the formulae A_2 is a factor depending on the number of observations in a sample; X is the average of all the group averages; D_4 is a factor for upper control limit on the chart for ranges; R is the average range. This chart shows that the machine was capable of producing to the required tolerance even though the setting was slightly low.

try, trigonometry, and preferably, an additional elementary course in quality control

(c) College mathematics for supervisors, including descriptive geometry, differential and integral calculus, and statistics.

Inspector's Duties

The inspector on the line, in most cases, simply writes down from five to ten measurements, adds and divides to obtain the average value, and subtracts the largest from the smallest to get the range. He plots the average and range on the chart, and takes action when the control limits are exceeded.

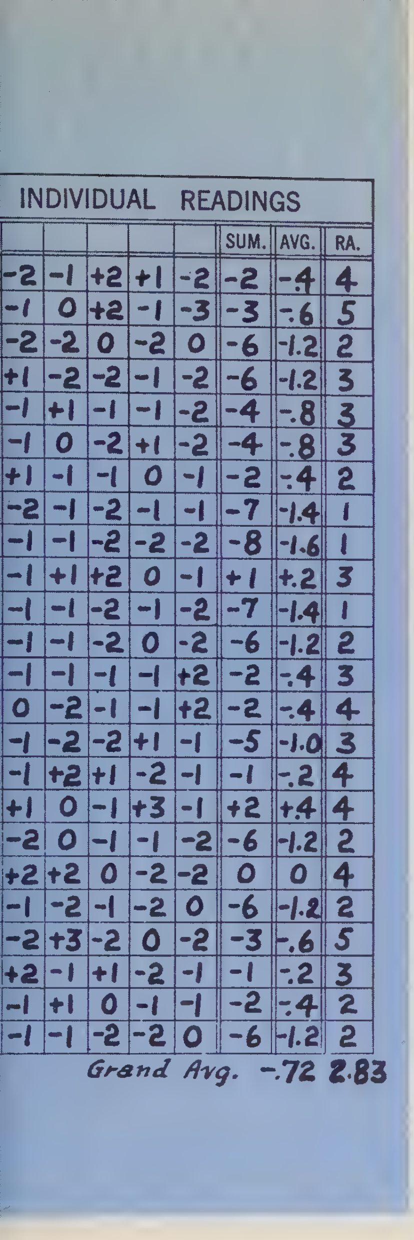
Technician's Duties

The work of the technician involves the calculation of control limits, analyzing control charts, selection of sampling plans, study of processes by the analysis of variance, significance tests, and correlation. The bulk of the mathematical work falls upon him.

Much of the mathematics of quality control has been reduced to relatively simple formulae, constants, and tables. For example, in establishing control limits, it is general practice to use plus and minus three standard deviations, or 3σ (three-sigma), from the average of 25 to 30 samples of usually five each. (The lower case sigma is the Greek letter used to denote standard deviation.) This results in a probability of 99.7 per cent that the process is in statistical control if all points are within limits. This calculation is simplified by using the average range and an appropriate constant as a close approximation of the standard deviation.

Tables of these constants are available giving values for each sample size. These values when multiplied by the average range, give the three-sigma values for averages (Fig. 3). The technician then substitutes in the following formula:

$$CL_{\bar{X}} = \bar{\bar{X}} \pm A_2\bar{R}$$



INDIVIDUAL READINGS							
					SUM.	AVG.	RA.
-2	-1	+2	+1	-2	-2	-.4	4
-1	0	+2	-1	-3	-3	-.6	5
-2	-2	0	-2	0	-6	-1.2	2
+1	-2	-2	-1	-2	-6	-1.2	3
-1	+1	-1	-1	-2	-4	-.8	3
-1	0	-2	+1	-2	-4	-.8	3
+1	-1	-1	0	-1	-2	-.4	2
-2	-1	-2	-1	-1	-7	-1.4	1
-1	-1	-2	-2	-2	-8	-1.6	1
-1	+1	+2	0	-1	+1	+.2	3
-1	-1	-2	-1	-2	-7	-1.4	1
-1	-1	-2	0	-2	-6	-1.2	2
-1	-1	-1	-1	+2	-2	-.4	3
0	-2	-1	-1	+2	-2	-.4	4
-1	-2	-2	+1	-1	-5	-1.0	3
-1	+2	+1	-2	-1	-1	-.2	4
+1	0	-1	+3	-1	+2	+.4	4
-2	0	-1	-1	-2	-6	-1.2	2
+2	+2	0	-2	-2	0	0	4
-1	-2	-1	-2	0	-6	-1.2	2
-2	+3	-2	0	-2	-3	-.6	5
+2	-1	+1	-2	-1	-1	-.2	3
-1	+1	0	-1	-1	-2	-.4	2
-1	-1	-2	-2	0	-6	-1.2	2
		Grand Avg.				-.72	2.83

here

$\bar{X}$ = average of each group

$\bar{\bar{X}}$ = grand average

$\bar{\bar{X}} \pm A_2\bar{R}$ = control limits for averages

($\bar{X}$ is referred to as, "X bar")

($\bar{\bar{X}}$ is referred to as, "X double bar").

he control limits for ranges are calulated in a similar manner with approriate constants.

By the use of these average and range harts, it is possible for a technician to etermine whether a machine or process capable of producing to the specified mits, whether a machine should be rrected, and whether the average and nge charts can be used as a record of ast quality.

FACTORS FOR COMPUTING CONTROL CHART LIMITS—SMALL SAMPLES

Number of Observations in Sample	Chart for Averages Factors for Control Limits	Chart for Ranges Factors for Control Limits		Chart for Individual Measurements Factors for Individual Measurements		Number of Observations in Sample
		Lower	Upper			
n	A_2	D_3	D_4	d_2	E_2	n
2	1.880	0	3.268	1.128	2.659	2
3	1.023	0	2.574	1.693	1.772	3
4	0.729	0	2.282	2.059	1.457	4
5	0.577	0	2.114	2.326	1.289	5
6	0.483	0	2.004	2.534	1.183	6
7	0.419	0.076	1.924	2.704	1.109	7
8	0.373	0.136	1.864	2.847	1.053	8
9	0.337	0.184	1.816	2.970	1.010	9
10	0.308	0.223	1.777	3.078	0.974	10
11	0.285	0.256	1.744	3.173	0.945	11
12	0.266	0.284	1.717	3.258	0.920	12
13	0.249	0.308	1.692	3.336	0.899	13
14	0.235	0.329	1.671	3.407	0.880	14
15	0.223	0.348	1.652	3.472	0.864	15

SYMBOLS

n = number of observations (Factors differ depending upon number of observations in a sample).

A_2 = factor for the control limits on the chart for averages.

D_3 = factor for the lower control limits on the chart for ranges.

D_4 = factor for the upper control limits on the chart for ranges.

d_2 = factor used to determine the spread of individual measurements.

$E_2 = \frac{3}{d_2}$

Fig. 3—Table of factors for computing control chart limits. In establishing control limits, technicians use plus and minus three standard deviations (three-sigma) from the average of 25 to 30 samples of usually five observations each. If all points are within limits there is a probability of 99.7 per cent that the process is in statistical control.

Other charts used are *per cent defective charts*, which show percentage of defective product being manufactured or received, and the *average number of defects charts* that show the average number of defects per part. The calculations involved with these charts are in general similar to those shown above.

Sampling Plans

In selecting a sampling plan to use on a particular job, the technician generally uses the Dodge-Romig single and double sampling plans, or the various plans specified by the armed forces. These tables are simple to use and involve no mathematics. Their derivation, however, is based on complex probability theory. Although the technician usually understands simple probability, he is not required to know advanced theory.

Standard Deviation

In many calculations it is necessary to use an accurate determination of the standard deviation. Two formulae for standard deviation are:

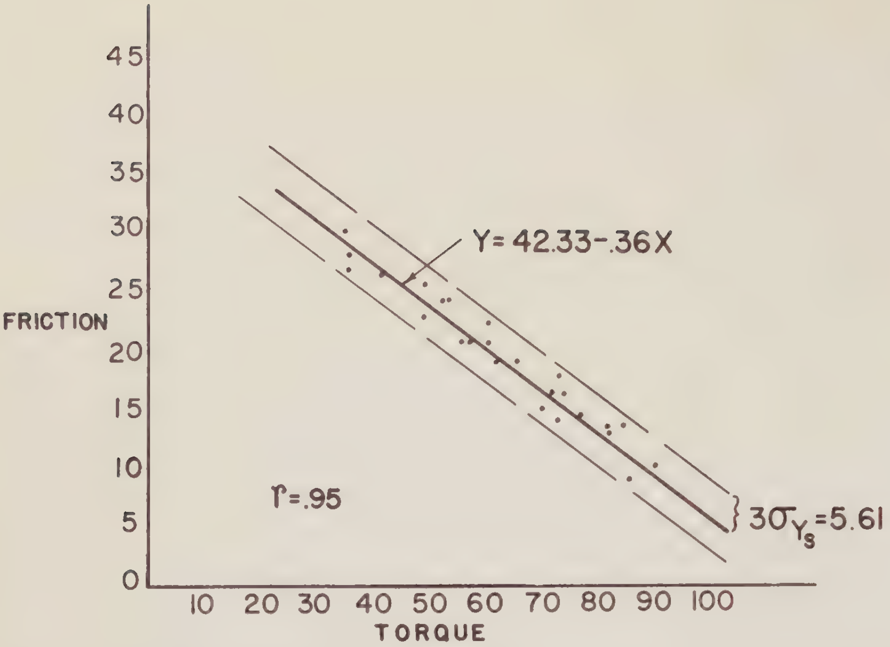


Fig. 4—Correlation analysis of friction versus torque. The correlation coefficient, r, is calculated by the formula: $r = K/\sigma_x\sigma_y$. With perfect correlation, $r=1$ and a straight line is produced with all points falling on this line.

$$\sigma = \sqrt{\frac{\Sigma(X-\bar{X})^2}{N}} \text{ for ungrouped data}$$

$$\sigma = \sqrt{\frac{\Sigma fd^2}{N} - \left(\frac{\Sigma fd}{N}\right)^2} \text{ for grouped data}$$

where

$\bar{X}$ = the arithmetic mean or average
N = the number of observations
f = the frequency of each class unit
d = the class interval (width of conveniently sized groups into which data are divided)
Σ = symbol of summation.

Calculation by use of the formula for ungrouped data is long and cumbersome. While the grouped data method is shorter, it can be seen that it would be too laborious for everyday use on control charts; however, it has other uses, shown below. These operations can be performed with a knowledge of only intermediate algebra.

Correlation Analysis

The use of the standard deviation as calculated above can be shown by an explanation of *correlation analysis*. Sometimes a certain physical characteristic of a material is important to the proper operation of a part. The problem is to sample incoming lots of this material to assure conformance to specification. However, no simple non-destructive method may exist for measuring that particular characteristic. In such cases, a different characteristic is sought which can be easily measured and can, in turn, be used as a measure of the first characteristic. Many times, the hardness of a steel part is used as a measure of the tensile strength, since a destructive test would have to be used to measure tensile strength directly. Correlation analysis is used to determine the closeness of this relationship.

In correlation analysis, a test, which in the above example would be destructive, is made on a sufficiently large sample of parts measuring each characteristic. The dependent and independent variables are then plotted, one as the abcissa, the other the ordinate.

If variations of the dependent variable are due only to the variations of the independent variable, perfect correlation exists. With perfect correlation a straight line results, with all points falling on this line. Since errors are possible in measurement, some measure or index must be established to evaluate the closeness of the two variables. This is called the *correlation coefficient*, and is usually referred to as r. When $r = 1$, there is perfect correlation; when $r = 0$, there is no correlation.

One method employed is as follows:

$$r = \frac{K}{\sigma_x \, \sigma_y}$$

where

σ_x and σ_y = the standard deviations of X and Y respectively

$$K = \frac{\Sigma(xy)}{N} - \overline{XY}$$

N = numbers of pairs of observations.

With $\sigma_x = \sqrt{\frac{\Sigma(X-\bar{X})^2}{N}}$

and $\sigma_y = \sqrt{\frac{\Sigma(Y-\bar{Y})^2}{N}}$,

it can be seen that the calculation is reduced to primarily multiplication anc squaring of numbers, which can be don on calculating machines. In fact, th whole problem can be set up on an automatic calculating machine.

By plotting the data obtained in a tes such as this, a scatter diagram is obtained, and the line of best fit can be calculated. For a straight line relationship, the *least squares method* is used, employing the straight line equation

$$Y = a + bX.$$

The a and b intercepts are obtained b solving these two equations simultaneously:

$$Na + b\Sigma X = \Sigma Y$$

$$a\Sigma X + b\Sigma(X)^2 = \Sigma XY$$

and then substituting in the straight lin equation to obtain the desired equatio of the line. For a correlation analysis friction versus torque, see Fig. 4.

Since there may be an error in th prediction of one variable from the othe it is desirous to know to what extent th actual values may be expected to var from the $Y = a + bX$ line. This is don by establishing three-sigma control limit for the data, and observing whether th points fall within these limits. The relationship used is

$$\sigma Y_s = \sqrt{\frac{\Sigma Y^2 - a\Sigma Y - b\Sigma XY}{N}}$$

For curvilinear curve fitting, the metho is usually more involved, depending o the type of curve being handled.

Analysis of Variance

One more important mathematica test employed in quality control is th *analysis of variance*, a technique used t determine whether the variation betwee two methods is due to inherent differences in the methods or is due to chanc causes alone. In this technique, the standard deviation for each set of data is calculated, and the ratio of the squares o the standard deviations is calculated This is called the variance ratio, or F.

By the use of variance ratio tables, vhich state the probability of a computed variance ratio existing by chance alone or given degrees of freedom, it can be letermined whether the significance level t which the computed variance ratio xists is satisfactory. Usually five per cent nd one per cent significance levels are ised, which provide about the same proection as afforded by two-sigma and hree-sigma limits on control charts.

The statistical techniques described so ar are a few of those most commonly ised in quality control. In more involved work, such as experimental testng, more advanced techniques are employed. However, for routine quality control work in manufacturing and inpection, the techniques discussed above ake care of 95 per cent of the problems.

Application of Quality Control to Designing

Since statistical principles are used to control dimensions in manufacturing, it s logical that they might also be applied o setting of tolerances in the design tage. This is another example of the vide application of quality control.

In a machine having three parts bolted ogether, the lengths of the parts are A, B, and C, and the individual tolerances are T_A, T_B, and T_C. The usual vay of determining the resultant variaion in the overall length of the assembly s by adding tolerances algebraically:

$$T_{Assembly} = T_A + T_B + T_C$$

This is true only if every piece is made o the maximum tolerance. But this is never the case. If the manufacturing process is statistically controlled, the engths will be normally distributed with nost of the pieces being at the mean of the tolerance. Under these conditions, 99.7 per cent of the assemblies will be vithin the tolerance, calculated as ollows:

$$T_{Assembly} = \sqrt{T_A^2 + T_B^2 + T_C^2}.$$

This assembly tolerance for a three-unit ssembly is 58 per cent of that tolerance alculated arithmetically and 71 per cent or a two-unit assembly. In practice, the lesired overall tolerance of the assembly s known, and the tolerances of the individual parts must be set. In other words, he problem is the reverse of the above. By this method, the tolerance of the parts of a three-unit assembly can be set approximately 70 per cent larger and still obtain the same assembly tolerance, provided the parts are statistically controlled in manufacture. For a two-unit assembly the tolerances can be set approximately 40 per cent larger. With good control, 99.7 per cent of the assemblies will be within the specified tolerance.

Mathematics Necessary for Quality Control Technicians

Some large firms use work sheets for each type of problem showing all the steps. All that is required is that the actual values be entered and the arithmetical operations performed. This method of solving routine problems is almost universally used in quality control, engineering, and design. Although it does not lead to the development of mathematical skill, it has the advantage of making it possible for anyone with a moderate mathematical background to solve complex problems. After the best solution has been worked out originally and set down in this manner, almost anyone with a fair knowledge of mathematics can fill in the work sheet and, barring arithmetical errors, come out with the correct answer.

The work of a technican or supervisor, in addition to solving routine problems, requires that he be able to think mathematically. Many times the successful interpretation of data and the solution of problems require that the technican or supervisor devise new methods of analysis, which cannot be done unless he possesses a fairly complete mathematical background. For example, he may have to design a new sampling plan to satisfy his particular needs, or he may find routine mathematical tests inadequate when used on data to determine significance or normality.

It is important, therefore, that technicians and supervisors have an understanding of the basic principles of mathematics. The technician must have a thorough training in high school geometry, trigonometry, and algebra which he will use extensively in the solution of equations, combinations, permutations, and binomial expansion. It is desirable that he have additional courses in quality control.

Actually, the mathematical background required for work in quality control is no different from that required in other technical fields. Anyone with a solid high school training in mathematics and wishing to enter the quality control field can take courses at colleges throughout the country. If the graduate has a college degree, especially an engineering degree, or if he was a mathematics major, he can take post graduate courses in statistics that will prepare him for the highest positions in quality control.

Conclusion

Statistics is an effective means of interpreting variation. A large portion of the statistician's work involves breaking down variations into their several elements and grouping together the variables which may be the result of a single factor.

Correct, scientific sampling is one of the requisites of effective statistics. It involves the use of the theory of probability to control and measure the reliability of useful statistical information. By utilizing the numerous charts and graphs designed for statistical work and applying a knowledge of mathematics, the statistician in industry has become an asset to industrial production and economy.

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Methods Engineering for More Effective and Economical Use of Manpower

By R. D. McLANDRESS
Manufacturing Staff
Central Office

Answering the basic question: How to do it?

The methods improvement function is not new. Man has searched since the dawn of reason for better and easier ways of performing work. Methods engineering as an aid in developing better and easier work methods is, however, relatively new. Engineers in this field are equipped with an extensive knowledge of fundamental techniques for eliminating wasted effort. Rather than prescribing detailed solutions, their work has outlined well organized programs which promote the use of these techniques in all phases of planning and manufacture. In a growing number of industries, successful methods engineering programs are cutting manufacturing costs.

INCREASING demands upon industry for improved and more complex products pose problems of increased costs which can be importantly offset through improvement in methods of manufacturing them.

In order to attain the required improvement, present operations must be studied continuously to discover existing losses. In planning new installations, every detail must be carefully checked to insure that the best possible conditions are established for effectively utilizing manpower, materials, and facilities.

In this task of analysis and planning for constant improvement, industry looks to methods engineering as an important aid in discovering ways to make more effective use of men, materials, and equipment. The techniques of methods engineering are directly concerned with systematic analysis and planning for maximum economy.

While relatively new when compared with other branches of engineering, methods engineering has become recognized as an essential function in planning efficient manufacturing operations.

Origin of Methods Engineering

The foundation of present day methods engineering began around 1900 when Frank and Lillian Gilbreth applied analytical techniques to the study of manual work in an effort to reduce wasteful practices. The improvements that resulted from this work established the need for the continual study of work methods. The unnecessary time consuming motions, excessive handling, and delays observed in these early studies still are the basic problems to be solved in most of today's manufacturing operations. These losses become increasingly more important with increased volume and higher wages.

Recognition of Need in General Motors

Methods engineering activity in General Motors began a number of years ago when the management in several GM Divisions became interested in statements made by industrial engineers that savings varying from ten to 40 per cent could be made in manufacturing plants through the elimination of wasted effort. The investigation prompted by these statements disclosed that they were essentially true; in fact, in some instances such forecasts were found to be conservative in the case of operations which were analyzed from the motion economy viewpoint. Thus the need became evident to apply motion economy analyses to all operations. To accomplish this, the Divisions carried out carefully planned programs for training their organizations in the application of motion economy principles. Improvement accruing from this approach resulted in the establishment of a continuing methods engineering activity.

Methods Engineering in General Motors Today

At the present time, all Divisions of General Motors are using methods engineering techniques in the *improvement of existing operations*. In addition, there is a growing use of these techniques as an aid in *planning new installations*.

Methods engineering is defined as the systematic analysis and planning for the effective and economical use of man power considering the economical balanc between manpower, material, facilitie and product. Methods engineerin activity throughout General Motors coordinated through an inter-Divisiona committee which meets at regular inter vals to discuss common problems an exchange information to insure the use o the most up-to-date practices througho all operating Divisions.

In the typical Divisional organizatio a Methods Engineering Department established to coordinate the over- Divisional methods engineering progra and to provide specialized analytic services where needed.

A long range methods engineerin program in a Division includes thre major phases. These phases are:

- *Training* of the organization
- *Improving* of existing operations
- *Planning* for new installations.

In the training phase such people a product designers, tool engineers, pro duction engineers, and manufacturin supervision are provided with an unde standing of methods engineering prin ciples and techniques. These principle and techniques aid in the discovery o conditions which result in excessive us of manpower.

In the improving phase everyone in th organization is encouraged to apply th principles and techniques of method engineering to existing operations i order to reduce losses.

In the planning phase methods engi neering principles and techniques plus th experience gained in the improving phase

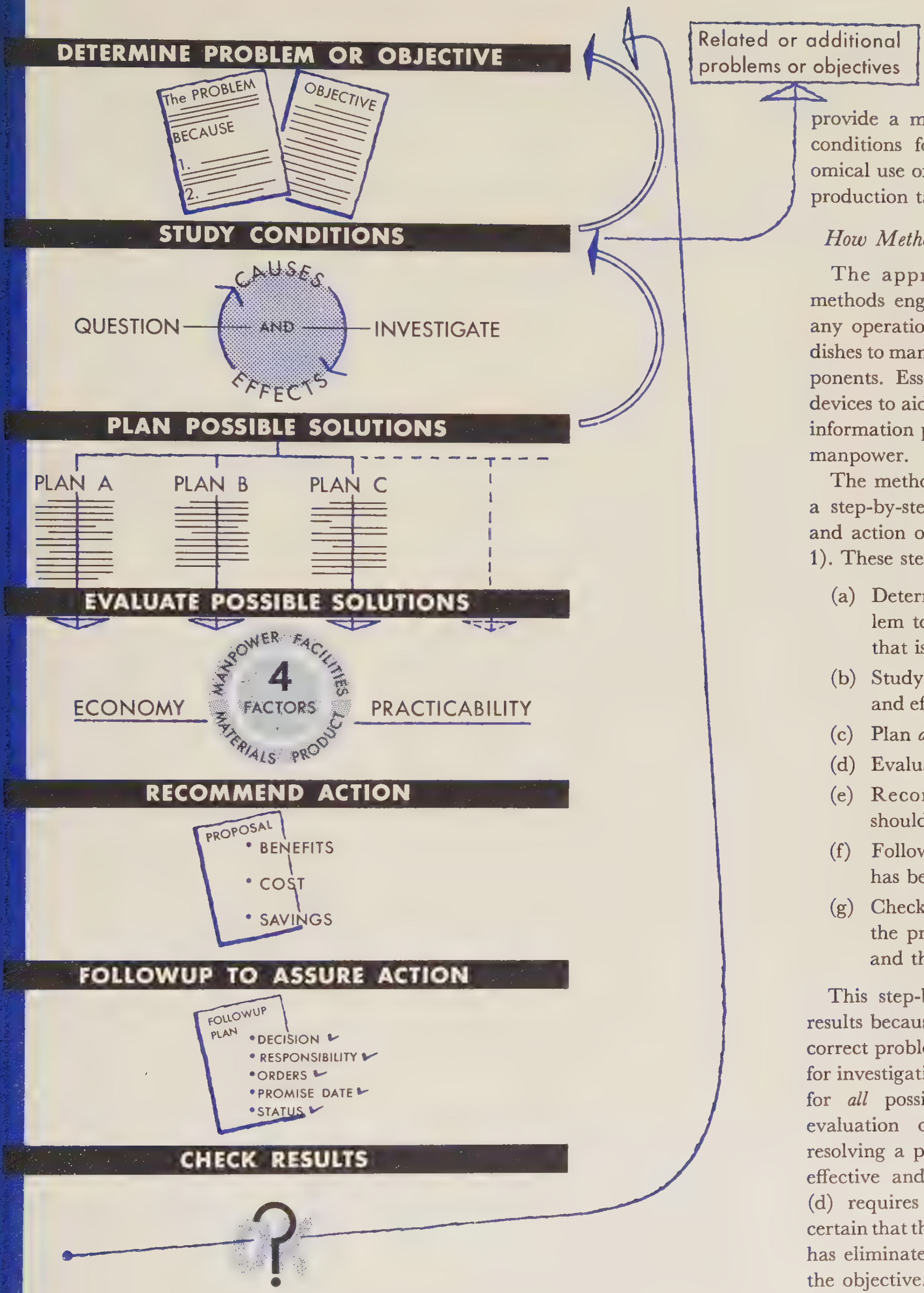

Fig. 1 — The methods engineering approach, developed by The GM Methods Engineering Committee and the Work Standards & Methods Engineering Section, Manufacturing Staff, is a step-by-step plan for logical analysis and action on methods problems. This plan is applicable to both operations planning and operations improvement. Detailed information on each of the steps is outlined in manuals which are made available to the Divisions.

provide a means of establishing proper conditions for the effective and economical use of manpower at the start of a production task.

How Methods Engineering Is Applied

The approach and techniques of methods engineering can be applied to any operation from washing the dinner dishes to manufacturing automobile components. Essentially the techniques are devices to aid in gathering and analyzing information pertaining to effective use of manpower.

The methods engineering approach is a step-by-step plan for logical analysis and action on a methods problem (Fig. 1). These steps are:

(a) Determine the nature of the problem to be solved or the objective that is desired.

(b) Study the conditions—the causes and effects related to the problem.

(c) Plan *all* possible solutions.

(d) Evaluate these possible solutions.

(e) Recommend whatever action should be taken.

(f) Follow-up to assure that action has been taken.

(g) Check the results to insure that the problem has been eliminated and the objective attained.

This step-by-step plan assures better results because it (a) places emphasis on correct problem analysis as a sound basis for investigation, (b) encourages a search for *all* possible solutions, (c) insures evaluation of each possible way of resolving a problem aiming at the most effective and economical solution, and (d) requires a check of results to be certain that the proposed corrective action has eliminated the problem or achieved the objective.

Useful Tools

Methods analysis techniques are established procedures used in methods study which aid in the investigation, recording, and analysis of information regarding operations. There are several of these techniques, and they are designed to record information in varying degrees of detail. The selection of a technique depends upon the degree of refinement necessary in a specific problem. These techniques are: possibility analysis, flow process analysis, act breakdown analysis, method-time analysis, movement-time analysis, and film analysis.

The *possibility analysis* provides for the systematic investigation of operations through the use of selected questions which focus attention on the specific factors which are indicators of methods problems. For example, possibility analysis sheets are used to question worker movement, material handling, plant layout, equipment design, and job set-up. It is the most general of all the techniques.

The *flow process analysis* records the steps involved in a series of operations by using standardized process symbols. This particular analysis may use one or both of two forms for recording information: the process chart and the flow chart. The process chart is a listing of each step in the processing of the part or object being studied. The flow chart is a diagrammatic recording in terms of area taking into account each step in the manufacturing of an object.

The *act breakdown analysis* describes and relates the left and right hand activity of the operator. This analysis is used to record a present operator method, to establish a description of a proposed method, or for comparison of various operator methods.

The *method-time analysis* is a technique which graphically relates method and time. The activity under study is classified into increments of work which are charted on a linear time scale. A study of this chart helps to determine how to group activities in order to result in the most effective use of man or machine time.

The *movement-time analysis* records and analyzes operator method in terms of movements related to time. Each movement of the operator is recorded along with the assigned time for that movement, including all waiting time and delay factors. Each movement is identified as to its type, length, and conditions under which it is performed.

Film analysis, often called the micromotion technique, records information regarding operations under study through the utilization of motion picture filming. An accurate measurement of method in terms of time is obtained by counting the film frames. Ranges of filming speed used are from one frame in several seconds to 1,000 frames per minute. These films are used as records of past and present methods, as a medium of exchanging information between plants and Divisions, and as an accurate means for detailed measurement of method in terms of time. Film analysis is the most specific of the techniques.

Conclusion

Long range methods engineering programs have produced desirable results in General Motors where each Divisional program is tailor-made by the Division's own personnel who know and understand operations of that Division and are trained to adapt the fundamentals of methods engineering to their own particular manufacturing problems. These programs result in annual savings running into millions of man hours.

A number of other advantages may be cited, in addition. These include: reduction in operator learning time, improved quality, reduced scrap, stimulated rate of improvement, a high degree of safety, and more active teamwork between production supervision and departments servicing the manufacturing areas.

Methods engineering is recognized as an essential function in analyzing and planning operations for effective use of manpower and the proper man-machine relationship for maximum economy in manufacturing.

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Fig. 1—The 47-in. high Corvette has low c. (18 in. from ground) and low moment of inert relative to wheel base ($k^2/ab = 0.62$).

No universally accepted definition exis for a sports car. It is generally accepte however, that the engine must cruise 70 mph with less than 2,500 ft/mi piston speed. Corvette (Fig. 1): 2,04 ft/min at 70 mph. Power-weight rati must be better than 25 lb/hp. Corvett 21 lb/hp. There must be ample brake Corvette brakes give an energy dissipatio figure of 1.27 hp/sq in. of lining in crash stop on a dry road from 60 mph Other desirable sports car qualities concern appearance, riding, and handling For example, the weight distributio between front and rear must be close 50-50 percentagewise. Corvette, in running condition with unloaded trunk a two passengers: 53 per cent front; per cent rear.

THE whole history of road vehic from the 17th century onward h been one of continual see-sawing design between ostentation and convenience, and the sports car in principle nothing new. The 17th century four-hors coach was ostentatious, costly, an cruised at some 5 mph. Its successor w the two-seated chariot, which improve speed to about 7 mph. The newly rich the 19th century liked the light, tw wheeled, two-seated vehicles which ha even higher performance, but wer slightly dangerous in the hands of fool Lightness featured wheeled vehicles unt the oncoming of motor cars in the latte years of that century.

Motor cars first were innocent c weather protection, but then came th semi-closed touring car which finall gave way in the 1920's to the sedan. Fo years this appeared the complete solution, but it did not please the tendencie of the young—always desperate t escape the chiding voices of their elde in the rear seat.

The eternal discontent of yout demanded once more a car which coul *xcerpts adapted from —*

The Evolution of a Sports Car: The Chevrolet Corvette

By MAURICE OLLEY

Chevrolet Motor
Division

Ir. Olley appeared before the October Society of Automotive Engineers Detroit ection meeting to tell, for the first time, the engineering story of Chevrolet Motor ivision's newest production automobile, the sports car Corvette. Requests for reprints f the full paper may be directed to: Engineering Department, Chevrolet Motor Division, etroit 2.

A sports car is for fun; requires careful engineering

ig. 2—Weight of Fiberglas body is 411 lb. iberglas weighs 0.05 lb/in^3.

e opened to the weather. The result: he roadster, the direct ancestor of oday's sports car.

The roadster's successor was the conertible of today. One step further is the ue sports car itself. It is small, low, and ght, without even a pretense of rear assenger accommodation. The main eason for a sports car: it is fun to drive.

The Corvette body (Fig. 2) consists of laminated construction of glass fibers npregnated and bonded by a clear astic, which, when an activator is dded, sets itself into a solid panel ther like plywood. Single experimental odels can be made by preparing Fiberas forms directly from the plaster mold nd building up the panels from layers of ass cloth laid in these forms. In producon, matched metal dies can be used ikewise various bag methods using acuum or air pressure). A rough mat is repared before insertion in the dies, an peration similar in some ways to tire anufacture. The setting process may be ccelerated by heating the dies in which e panels are formed.

The result is a very usable body, somehat expensive, but of light weight. It ands up to abuse, will not rust, will not umple in collision, will take a paint nish, and is relatively free from druming noise. The Corvette body, comete, weighs 411 lb.

The Corvette's engine is the standard 235 cu in. Chevrolet engine modified for increased performance and to use premium fuel (Fig. 3). Compression ratio is 8 to 1. The design provides a high lift camshaft, with metal timing gears. Mechanical tappets may not be absolutely necessary but are used because of engine speeds which are known to exceed 5,000 rpm. Heavy valve springs are required. The rocker cover has the oil filler moved back for access under the rear opening hood. Valve timing is modified for the higher engine speeds. Three individual side-draft carburetors are synchronized by the throttle linkage, and supply each of the siamesed intake ports. The exhaust manifold is dual.

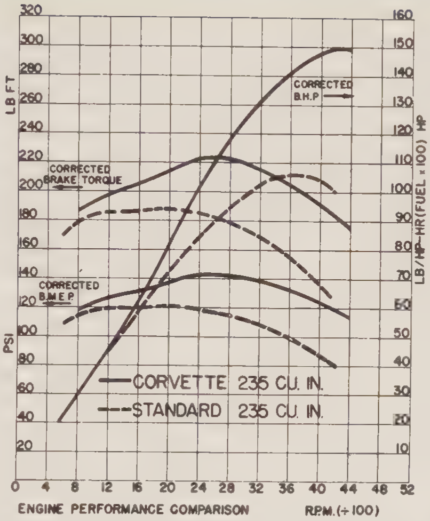
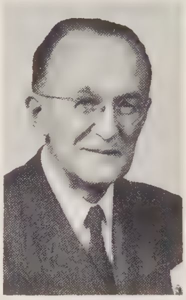


Fig. 3—Modified line 6 Chevrolet engine yields 150 bhp for 3,150 lb Corvette, loaded weight.

The Corvette's transmission is a modification of the standard Powerglide automatic transmission, with oil pressure increased to handle 223 lb-ft of torque and a shifter valve which gives a full throttle upshift at 4,500 rpm or 55 mph, and a full throttle downshift to a 1.82 low ratio up to 47 mph. The use of an automatic transmission in a sports car might be questioned, but sports car desires are shifting away from the austerity of the pioneer towards the luxury of modern ideas.

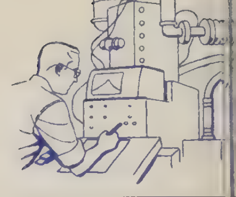
The sports car is a serious form of transportation. It ranks with the chariot, the tilbury, the curricle of the 1800's, with the roadster of the 1920's. It is a necessary step in providing convenient, lively transportation in a small package for two people.

Also it is a bit of adventure, fun to drive, fun to build.



MAURICE OLLEY, who began as a General Motors engineer in 1930, is director of research and development, Chevrolet Motor Division. His education and early engineering work was in England where he became personal designer for Sir Henry Royce. Later he became chief engineer for Rolls Royce in America. From 1930 to 1937 he was successively special projects engineer for Cadillac Motor Division and for the General Motors Corporation. During the World War II years he served as engineering representative for Rolls Royce Limited in U. S. A. (aircraft engines) and was later appointed to the British Ministry of Supply (tanks). From 1945 until joining Chevrolet in 1952, he was technical consultant to Vauxhall Motors, England. He has appeared before, and been active in, the principal U. S. and British automotive societies. His GM engineering work has resulted in 19 U. S. and seven Canadian patents.

Engineering Personnel Management in a General Motors Division



The elements which go into the making of a good professional home for an engineer are difficult to define. Industry generally recognizes engineering as a valued and respected field and efforts are being made everywhere to make the individual engineer's niche in the community of professions a favorable one. Each Division of General Motors has its own individual plan for the progress and greater contribution of its engineers. No two Divisions, in this decentralized organization, have exactly the same practices, but in each there is a common appreciation of the individual engineer. The Research Laboratories Division is in many ways typical of all the other Divisions. Its management has, in all of the Division's years, recognized the individual engineer as an asset and has built up practices and activities which are designed to establish a working pattern and atmosphere from which both the individual and the organization can extract maximum benefit.

From a manufacturing standpoint, General Motors is fundamentally dependent on the engineers in research, product development, and production for maintaining and improving its competitive position. The organization is, therefore, vitally interested in the various problems concerned with engineering personnel.

Every engineer is proud of his profession and the temptation is ever-present to extol the virtues of the engineer too highly. Therefore, it is emphasized at the beginning that the writer appreciates the value and importance of people in sales, finance, personnel, production, and the many other activities of General Motors. All are members of a team in which no member can be successful without the others.

Much is said currently about a shortage of engineers and the shortage is forecast to persist for some years to come. The facts leading up to this situation are beyond the scope of this commentary.

It is certain, however, that industry is using more and more engineers. In 1900, there was one engineer to each 250 employes. At the present time there is an average of one engineer to each 62 employes in industry. In General Motors there are almost 15,000 engineering employes engaged in Corporation research and product engineering, which make a force as large as all the employes of some of the organization's production Divisions. The number of engineering employes is still growing because of the greater technical complication of products and processes.

Engineers are probably the fastest growing professional group in our economy. They likewise represent the scarcest group of manpower which General Motors employs today. Therefore careful attention is given to the problems which are faced by the large engineering force in General Motors. The research and engineering programs underway will require a still further expansion of General Motors engineering groups in both
manufacturing Divisions and in
research and advanced engineering St

The Engineer's Characteristics

Before discussing some of the progr
which are desirable or even necessar
recruit, train, and develop engineers,
appropriate to consider the fundame
qualities of engineers. Most engin
have these qualities to a higher or le
degree. The qualities probably are pa
inherent characteristics emphasized
the nature of engineers' education
work. The term *engineer* is used in a br
sense in this paper and includes me
lurgists, chemists, physicists, and ma
maticians, as well as those in the u
mechanical, electrical, and chem
engineering classifications.

The engineer is intellectually hon
He deals with nature's laws, which

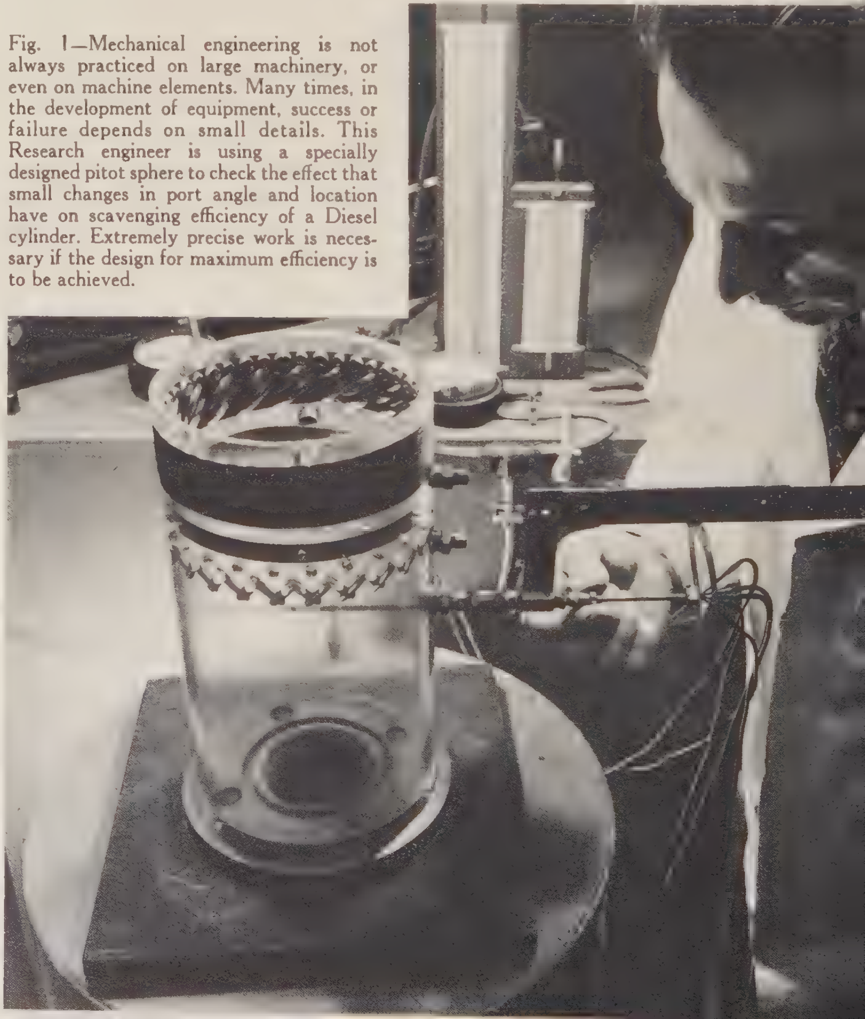


Fig. 1—Mechanical engineering is not always practiced on large machinery, or even on machine elements. Many times, in the development of equipment, success or failure depends on small details. This Research engineer is using a specially designed pitot sphere to check the effect that small changes in port angle and location have on scavenging efficiency of a Diesel cylinder. Extremely precise work is necessary if the design for maximum efficiency is to be achieved.

By CHARLES L. McCUEN
Research Laboratories
Division

A general manager looks at his engineering personnel

:ual, unchangeable truths. He lets the
:s decide and does not take things for
nted (Fig. 1). The engineer has
rned to analyze and find logical solu-
ns. He is not inclined to jump to con-
sions and does not often fool himself.
is, likewise, not easily fooled by
ers since he expects ideas to be proved.
Engineers have a strong quality of
ability and loyalty. They are by
ure inquisitive and have a strongly
reloped sense of curiosity. Engineering
reative work and engineers are creators.
Since most engineers are individualists,
y have to be treated as individuals.
ey are trained to work on their own
l to be responsible personally for their
ılts. The fact that they are coopera-
: means that they work well in a team.
Engineers are proud of their profes-
n and value and expect professional
rancement just as surely as they do
ancial advancement. Professional rec-
nition includes such things as partici-
ion in technical society activities,
sentation of technical papers, appro-
ate personnel classification, and the
en and one items that set the engineer
as belonging to the organization. He is
ck to accept opportunities for further
ication. He performs his work assign-
nts well; however, his professional
ning may cause him to dislike certain
k assignments which he feels should
re rightly be accomplished by persons
hout a similar level of training.
The foregoing should not imply that
engineer is either a superman or a
uliar breed. In most respects he is a
d, solid citizen and a conscientious
ker who gets along harmoniously
h other groups.

How Engineers Join Industry

With this as a background, considera-
n may be given to some of the pro-
ms which the Research Laboratories feels are desirable in an engineering organization. By giving the results of experience and by describing the programs, it is possible to discuss the problems of engineering employes as they are viewed at the Research Laboratories. The programs mentioned are those which have been used to build a good productive organization. Other General Motors Divisions are aware of the problems and have active programs also. The things discussed here have been in successful operation for a number of years, and have been very well received by the Research workers.

Fig. 2—The chemical engineer in an industrial research laboratory has an unparalleled opportunity for expressing his individual interests and ability. The challenge of keeping ahead of an ever-changing technology is a difficult one to meet. The illustration shows the initial stages of a project on thermal diffusion of liquids.

The first and primary job is that of procuring high quality men who have the potential for future advancement (Fig. 2). General Motors' basic personnel policy is to promote from within. Men with the ability to grow and assume broader responsibilities are hired at the beginning level so that it is not often necessary to go outside the organization to fill an important position. It goes without saying that the men procured today will determine the caliber of the organization tomorrow.

A personnel representative can feel as great a sense of accomplishment when a man that he has hired assumes later on an important position in the Corporation as a research engineer does when he makes an important discovery. For an organization is only as good as the men in it. The most valuable asset of an engineering organization is its experienced, intelligent men. Other assets can be replaced in a relatively short time, but the building of an efficient staff takes many years. This fact comes into sharp focus when a business is confronted with

Fig. 3—A group of young engineers attending a lecture in mathematics conducted by a Research staff member.

a major disaster. An organization may lose its plant and tools through some misfortune but the fine organization remains. Its people can immediately set to work to rebuild the tools destroyed. They can rebuild the plant and get back into production in a fraction of the time it would take to replace the operating organization. The experience, knowledge and abilities that were accumulated over the years remain intact.

Personnel men perform the first steps in building the organization. They represent General Motors and its Divisions to a prospective employe. When they hire young engineers, they are working for the future just as Research workers are when they carry on fundamental long-range projects.

For many years the Research Laboratories Division has had several definite programs for procuring young engineering graduates. No one method or source is considered sufficient. The force should represent a broad background of education and experience. The Research Laboratories' engineers come from 80 American and foreign engineering colleges.

For many years this Division of General Motors has obtained men through the cooperative form of education. The first of these men came from the University of Cincinnati, where cooperative education was pioneered. Many have come, of course, from the General Motors Institute, which is operated under the cooperative system.

Another activity is the summer student program. A number of engineering and science-major students are employed during the summer between their junior and senior years. Those students considered promising are offered jobs after their graduation. The excellent showing of former summer students reflects the more careful screening possible through observation of their work over an entire summer period.

The method most recently employed is the direct procurement of engineers from colleges and universities for a college-graduate-in-training program. It is recognized that the need for men arises every month of the year, but that graduates are available only in June and to a lesser extent in January. The plan is, therefore, to decide how many men will be needed for the next year and hire them when they are available. They are obtained through the General Motors college recruiting program in which Research has participated since its inception.

The new engineering graduate is put into the training program for one year, during which time he is moved from department to department quarterly. By the end of his training program his aptitudes and abilities have been discovered and he can more intelligently be given a permanent assignment. This method of determining a man's future field of work has proven to be a tremendous advantage, both to the individual and to the organization. This
an excellent method for building
organization for the future.

The Research Laboratories Divisi
also supports graduate fellowships at
number of colleges in subjects in whi
General Motors has an interest. Wh
there is no obligation on the part of
school or student, men with advanc
degrees are often obtained for spec
research work from this source.

After the young engineer has co
pleted his year of training, he must
be forgotten or lost in the organizatio
It is emphasized to the new emplo
that there are unlimited opportunit
for advancement within the Gene
Motors organization. A number of pr
grams are aimed at promoting the in
vidual's professional and personal dev
opment.

Engineer Activities

For the younger engineers there is
program of monthly technical meetin
which they plan and operate themselv
Technical papers are given either by
young engineers or by more experienc
engineers who are invited to these me
ings. These young men gain valua
experience in organizing and conducti
meetings. They develop the ability
write papers and to speak before
audience.

The Laboratories also supports cour
in technical subjects taught by profess
from schools in and near Detroit. The
may be attended by any engineeri
employe. The Division also gives cours
which are taught by Research st
members (Fig. 3). Examples of the
courses are advanced dynamics, phys
of the solid state, hydraulic machine
and advanced thermodynamics.

Recently an evening study plan h
been inaugurated at colleges in t
Detroit area for those who wish to fu
ther their education. A number of R
search engineers have obtained advanc
engineering degrees through eveni
courses. The employe is reimbursed
his tuition, provided he meets certa
requirements of the plan.

The Research Laboratories also h
sponsored non-technical courses in ma
agement and human relations as giv
by the General Motors Institute. Seve
hundred employes participate in this
the-job training at one time.

These educational activities are tan
ble evidence to the engineer that ma

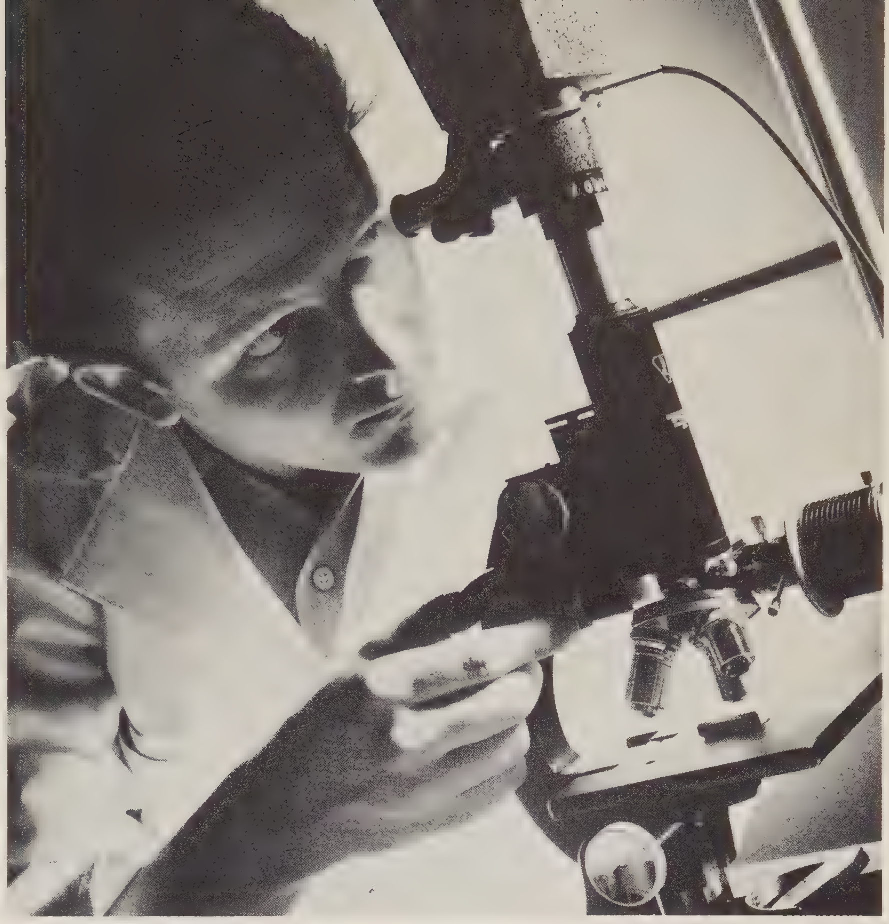


Fig. 4—Typical of the type of research job that cannot be rated on a time scale is this fundamental study of friction. The specimen being lined up under the camera is part of a study in which information is being sought on what is friction, why it exists, and how it can best be used to advantage or eliminated where it is troublesome.

ement considers him an important part
the organization and that his super-
ors are interested in his professional
d educational advancement.

A program of social and recreational
tivities also is maintained. The year-
und activities range from baseball in
summer to bowling in the winter.
cnics, dances, supervisors' dinners, 25-
ear Club, and other activities provide
neans of social contact so that employes
come better acquainted.

requent Periodic Employe Appraisals

Very important to the engineer is a
riodic employe appraisal system. This
an essential part of any engineering
rsonnel program. A quote from the
struction sheet for supervisors gives a
cture of the system's aims:

> "The assumption is made that the
> value of an employe, which we have
> chosen to call Work Performance,
> can be adequately appraised in
> terms of four basic components.
> These components are, in the order
> in which they appear on the ap-
> praisal form, *ability*, *interest*, *industry*,
> and *human relations*. They contribute
> to the overall rating of Work Per-
> formance."

A number of activities are underway
d policies in effect which might be
nsidered those of the established engi-
er, although the junior engineer is
ich concerned too. There must be
tivities for all classifications and ages
there is to be a successful overall plan.

The Research Laboratories Division
els that it is desirable to encourage the
her Divisions of General Motors to
nploy Research engineers when they
ach the point where promotions are
t open in their own organization.
hen the Divisions have openings of
eater responsibility, the Laboratories
ould much rather see its engineers
ansfer to another part of General
otors than to look outside for further
vancement.

As a result of this policy, men with
esearch training and experience now
cupy important positions in most of
Divisions. This transferring of em-
oyes who are ready for advancement
a most important policy to Research
gineers. If sufficient opportunities do
t develop locally, they feel that they
n settle on a career with General
Motors with unlimited opportunities. (The practice of inter-Divisional transfers is not uncommon throughout General Motors.)

Professional Incentives

It is well understood that engineers value the opportunity for professional recognition both inside and outside the organization. Monthly technical meetings for established engineers help them inside the organization. At these meetings technical papers are given on developments in various Research Laboratories Departments. They help to keep everyone informed and give an opportunity for engineers to present their results.

Publication of technical papers in the periodicals of, or before, various technical societies is encouraged. As many as 50 papers and talks a year may originate from the Division's engineering employes. This activity has several desirable results. It places a record of Research accomplishments in authoritative technical literature, thus enhancing the technical reputation of General Motors. It gives the engineer-author credit before his professional group and gives him greater professional stature.

Participation in technical society activities also is encouraged. Many engineers are members of important society committees in which they represent General Motors interests. A number have become nationally known authorities in their field through such activities.

There exists a liberal policy on travel to attend technical meetings. Research Laboratories representatives are sent where it is thought that mutal benefit will accrue to the society and to General Motors. It is felt that this expense is justified in many ways. Of course, the engineer is pleased to meet and get acquainted with others in his field of work. In so doing he usually acquires information which is highly valuable to the progress of Laboratories projects.

Research Associate Program

Very recently a new plan has been inaugurated for the promotion of senior engineers who do not want advancement to the management level or are considered to be more valuable in nonmanagement positions. A poor administrator often has been made from a good engineer because this was the only way open for promotion. In the past the only way open to recognize good technical performance was to promote to supervisory jobs. It has long been recognized in the professional field that there should be an alternate route giving equal prestige, authority, and privileges. This has been true in other professions such as the legal, medical, and educational fields.

The Research Laboratories, therefore, has added a new salary classification with the designation *research associate*. This classification is reserved for those senior research workers who are more valuable in their technical specialty than they would be as administrators. This new classification is on a par with departmental management. It is anticipated that the new classification will do much for the productiveness and personal well-being of the senior engineer who feels that there is no room for further promotion.

Accumulated Technical Knowledge

While there is still much that can be done to make the maximum use of engineers and build strong engineering organizations, a good start has been made. The reaction of the Division's engineers has been enthusiastic and lasting. The practices have proved to be sound business and have resulted in more interest and better work performance. This reputation as a good employer gets back to the student in the colleges, and the Division has been able to recruit a very large number of graduates in the face of the present shortage of engineers. Research can look to the future with assurance of having capable men ready to take over at any time it becomes necessary.

When one dwells on the potential of the several hundred young men now on the Division's staff, it can well make one feel humble. For this group represents almost 1,500 years of higher education in engineering and science to say nothing of the years of grade and high school training. In all, more than 5,000 years of education is represented by the Research technical force alone. When the accumulated knowledge represented by these 50 centuries of study is applied to current technical problems, it is no small wonder that the Research Laboratories Division has been reasonably successful in solving many of them.

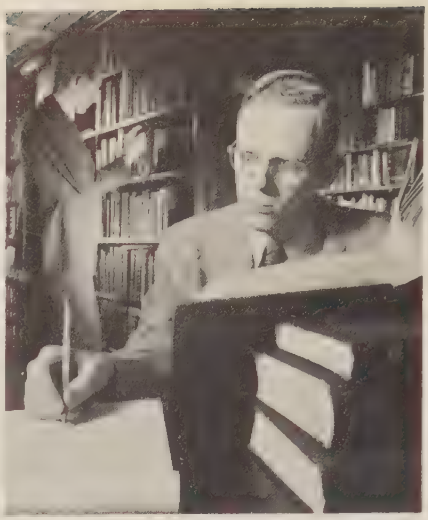


Fig. 5—Research engineers reading up on the latest information obtainable in the Laboratories' up-to-date technical library. Also available are the records of past experience to aid them in their current projects. The Research engineer spends many hours of his personal time in this intensive search for knowledge after he leaves the Laboratories.

Supervisory Responsibilities

Engineering has been a great force for benefiting mankind, for it is the application end of science. It is the engineer's responsibility to apply the facts of science to increase our standard of living by developing new and better things for more people.

It is the responsibility in management to continue to build engineering organizations so that General Motors' technical future will be as productive as it has been in the past. The junior engineer of today will be the chief engineer of the future. Current engineering procurement, training, and advancement programs largely determine the engineering future of General Motors.

This has been an attempt to describe the programs for giving the engineer an opportunity for professional advancement and recognition in one General Motors Division. Of equal importance is a competent group of engineering supervisors who understand the problems and administer them well. The supervisor, such as the department head or assistant, is the man in direct contact with the engineer. He is responsible for carrying out the programs and seeing to it that his engineers are kept informed and are encouraged to participate. A director of engineering training is responsible f
the administrative work involved in mar
of the personnel programs.

It is important to emphasize, howeve
that plans and programs cannot make
good engineer out of a poor one. T
evaluation of engineers cannot be mac
with the certainty that there is in evalua
ing someone in a routine, repetitive jo
In creative work there are no set stan
ards of measurement of job performan
and no scales of the time required
finish a job (Fig. 4). This means th
after all the known standards of emplo
evaluation have been applied, the fin
evaluation must be made by the supe
visor and management who have pe
sonal knowledge of the engineer's pe
formance and capabilities.

It is this factor of no-set-standar
which differentiates the personnel pro
lem of the engineer from that of employ
on more routine jobs. The engineer giv
more and, therefore, often expects mor
He does not work entirely by the cloc
for he often devotes hours after work f
reading technical literature, attendi
technical meetings, furthering his educ
tion by attending classes in technic
subjects, and thinking of his day's pro
lems. No really good engineer can clo
his mind to his work as he closes the do
to his laboratory office at quitting tim
(Fig. 5).

Evaluation of Engineers

One often contemplates the chara
teristics which made one man progre
many times faster than another, ev
though when they started work, bo
men seemed to have about equal abili
These characteristics, however they ma
be defined, are especially important
engineering.

Is it personal drive, the ability to s
things through to a conclusion, an i
quiring mind, a positive mental attitud
an optimistic approach, or the willin
ness to go beyond the ordinary? Perha
original ideas come easier to some peop
or maybe the ability to interpret te
results is a clue (Fig. 6).

There are many examples where tw
engineers started with equal opportu
ties and seemingly equal training ar
ability. Both would be considered e
cellent engineers with very good pe
sonal and professional qualifications. B
some hard-to-define quality made one
very successful engineer while the oth
just drifted along.

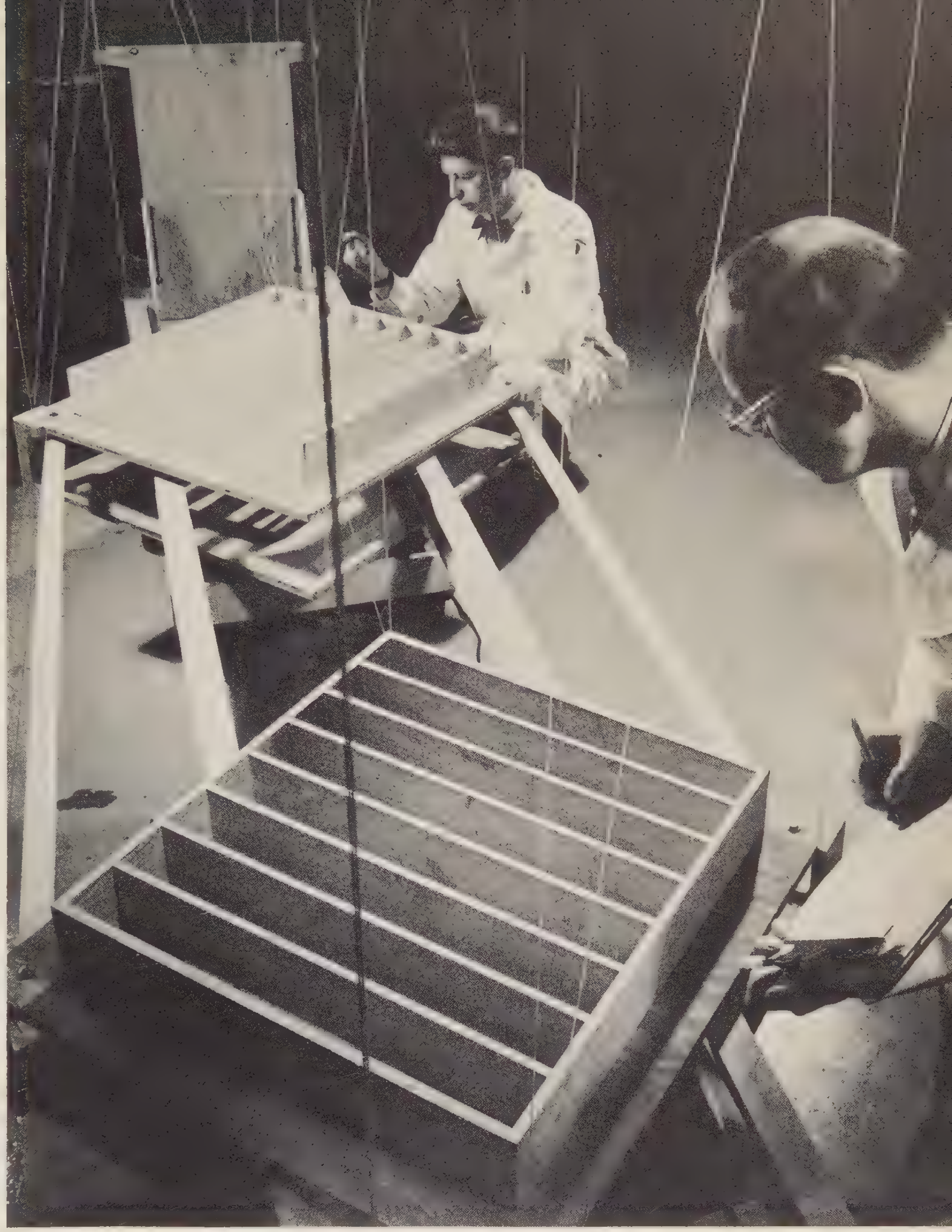


Fig. 6—Many times the research engineer must interpret an ordinary problem in an unusual manner to get the best results. One highly unusual application of industrial mathematics is pictured here. This string-suspended structure is a mechanical analogue of a differential equation illustrating a theory of why automobile brakes squeal. The engineers are observing the period of oscillation set up by an air stream blowing up through the vaned members to obtain values for substituting in the equation.

While the writer was with another eneral Motors Division, a crankshaft roblem developed and it had to be lved in a hurry because new-model roduction was soon to begin. The task as given to two good men. The first one d the crankshaft checked against the ueprint in every way. The dimensions ere correct, the metallurgy was right, d every factor seemingly accurate cording to the specifications. The cond man did likewise. The first man's port was that he couldn't see anything rong with the crankshaft and that erything looked all right to him. The cond man said that something must ave been missed because the shaft did il. He thought that it might be the lets and that he would like to try creasing their radius. When he did is, the crankshaft gave no further ouble.

Now, the first man continued as an gineer but never got beyond just being good employe. The second man re-ived promotion after promotion and came a very successful executive. What e differences were between these two en is difficult to define but the differ-nces were there, as events finally showed.

In another case, several very excellent oung engineers had worked for a num-er of years on a project to develop a etter engine oil filter. Several fairly od filters had been designed, but there ways seemed to be something wrong ith each commercially.

Finally one day in the cafeteria, one the engineers was toying with his tea p which had a few leaves in the bottom. wirling it so that the liquid rotated ound and around, he noted that the a leaves, which were only slightly avier than the liquid, collected on the de of the cup. Rather idly he discussed is with his luncheon companion, and ggested that this principle might make good oil cleaner for Diesel engines. With is single thought as a starter, they andoned the cleaner on which they d been working and built a centrifugal vice. In a rather short time as develop-ents go, they had a new type oil cleaner hich is soon to go into production. It is ch a good oil filter that it is impossible wear in the piston rings with normal eration of the engine. The result is a gh initial oil consumption. A method s been devised for wearing in the rings d then using the filter to keep the oil ean and reduce engine wear to a fraction of that which it had been before.

How would one evaluate the work of this man in devising this oil filter? What measurable characteristic or quality makes him successful where other men have failed? A personnel evaluation system, whatever it is, should select the exceptions and not just the average men. For it is the exceptional and superior man upon whom industry depends for carrying on progress in the future.

Summary

Engineers are individualists and must be dealt with on an individual basis. They cannot be grouped into one mold. To make the best use of engineering talent requires that management recognize that any engineering organization is only as good as its best men. It is the top engineers who set the pace and come up with the results, not the mediocre ones. Any good system of engineering personnel management should encourage the exceptional man to reach his full potential. It must be based on recognition of individual accomplishment and progress.

A Study in Applied Physics: Locating the Piston Pin to Minimize Piston Slap

By GILBERT BURRELL and
F. GIBSON BUTLER
Oldsmobile Division

A classroom method outmodes trial and error, speeds design

The change in direction of a piston during combustion is accomplished by a reversal of certain forces on the piston. One of the possible results is an audible piston slap. By properly locating the piston pin, the behavior of the piston may be controlled so that the slap tendency is minimized. An analytical method developed and used satisfactorily at the Oldsmobile Division demonstrates how the sound application of basic physics enables the pin location to be pre-determined and the slap tendency reduced. This method was first used in 1948 in connection with the development of the Oldsmobile Rocket engine.

ENGINE *piston slap*, a characteristic light knocking noise, is recognized readily by automotive engineers, mechanics, and many automobile owners. Moderate piston slap generally occurs only in a *cold* engine and during initial engine warm-up, then disappears when the engine is *hot*. Usually, piston slap is not harmful but may be a cause of annoyance and worry to the automobile owner.

The usual diagnosis of piston slap is excessive clearance between the piston and cylinder bore. Fig. 1 shows a sectional view of an Oldsmobile engine. While it is true that piston slap increases in intensity with increased piston-to-bore clearance, it is the task of the engineer to minimize or eliminate piston slap with the maximum piston-to-bore clearances which may occur during the life of the engine.

Causes of Audible Piston Slap

Audible piston slap is caused by the piston moving from the *minor thrust side* to the *major thrust side* of the bore near the top of the stroke during the *firing* cycle (Figs. 2a, 2b). The greater the piston-to-bore clearance, the louder the piston slap. It has been found that the manner in which the piston moves from side to side in the bore greatly affects audible piston slap.

The two factors which affect audible piston slap are: (a) piston-to-bore clearance and (b) the manner in which the piston moves across the bore near the top of the firing stroke.

Piston-to-Cylinder-Bore Clearance

There are three factors that affect or control the piston-to-bore clearance in a cold engine: (a) the difference in expansion between the piston and cylinder bore as the engine is raised to full output conditions, (b) the minimum allowable clearance with the engine operating full output, and (c) engine wear.

Even though the piston is made of ir with the same coefficient of expansion the cylinder bore, piston expansion w be greater because of cooling facto

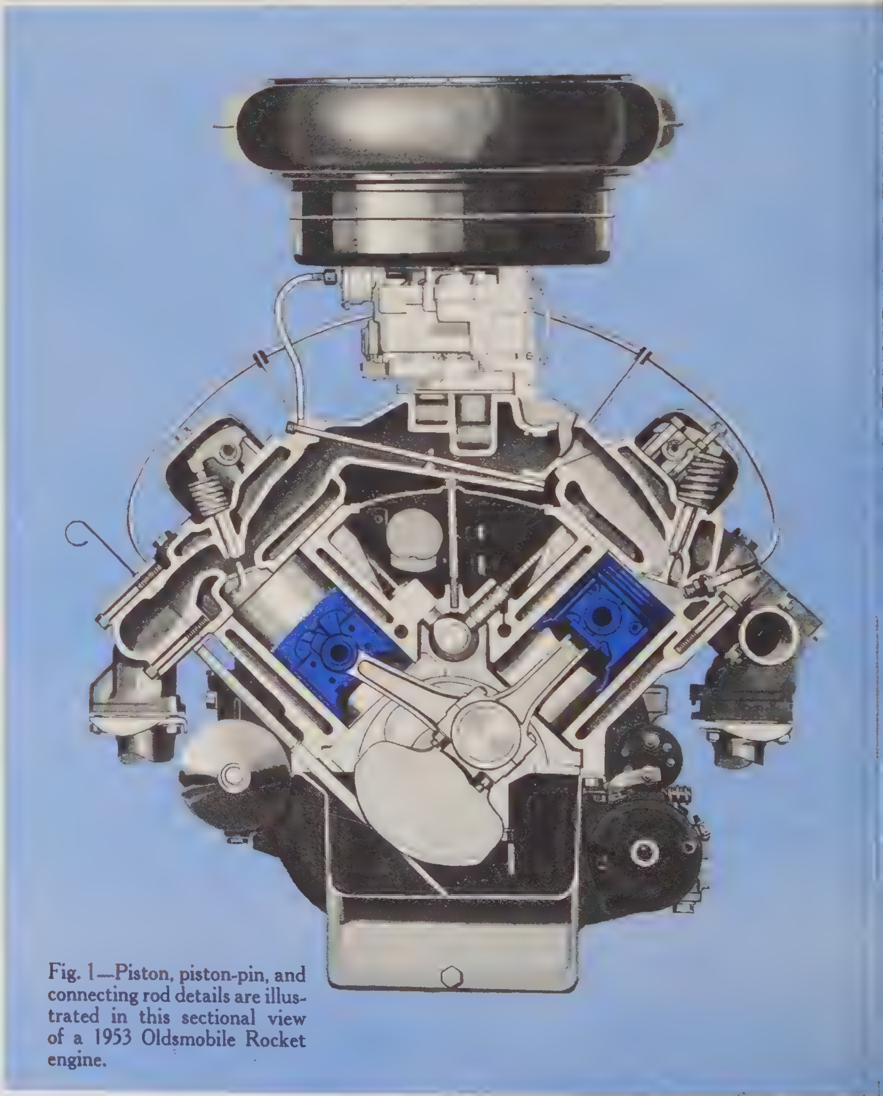


Fig. 1—Piston, piston-pin, and connecting rod details are illustrated in this sectional view of a 1953 Oldsmobile Rocket engine.

involved. Although both piston and bore are subjected to the heat of the burning fuel-air mixture, the cylinder operates at a cooler temperature because it is cooled directly by the cooling liquid while the piston is cooled indirectly by heat transfer to the cylinder bore through piston rings and piston skirt contact.

Aluminum pistons, operating in iron or steel cylinder bores, tend to accentuate the expansion differential between the piston and cylinder bore because of the higher coefficient of expansion of aluminum. Modern design aluminum pistons tend to minimize or correct for this difference by the use of a flexible skirt design or by having the skirt expansion controlled by steel struts or a steel band cast into the piston. However, there still is a resultant difference in expansion between the piston and cylinder walls.

The initial cold engine piston-to-bore clearance must consider the above mentioned expansion differential. In addition, the minimum allowable clearance with the engine operating at full output also must be considered. This minimum running clearance must be sufficient to maintain an oil film to prevent metal to metal contact which would result in high frictional losses and possible scuffing or seizure.

In the cold engine, the total piston-to-bore clearance includes the above two design factors—expansion differential and minimum running clearance—plus the increase in clearance caused by normal engine wear. This total clearance then must be recognized in any attempt to minimize or eliminate audible piston slap.

Piston Movement Across the Bore

As mentioned above, any audible piston slap will occur as the piston moves across the bore near the top of the stroke. Ordinarily, piston slap does not occur at the end of the exhaust cycle because the low pressure on the piston results in low side thrust and corresponding low lateral velocity. Consideration can be limited, therefore, to lateral piston movement near the top of the firing stroke. Normally, the top and bottom of the piston do not move across the cylinder bore together; either the top or the bottom moves first. It has been found that if the bottom of the piston moves after the top of the piston, audible piston slap results. Conversely, if the bottom of the piston moves

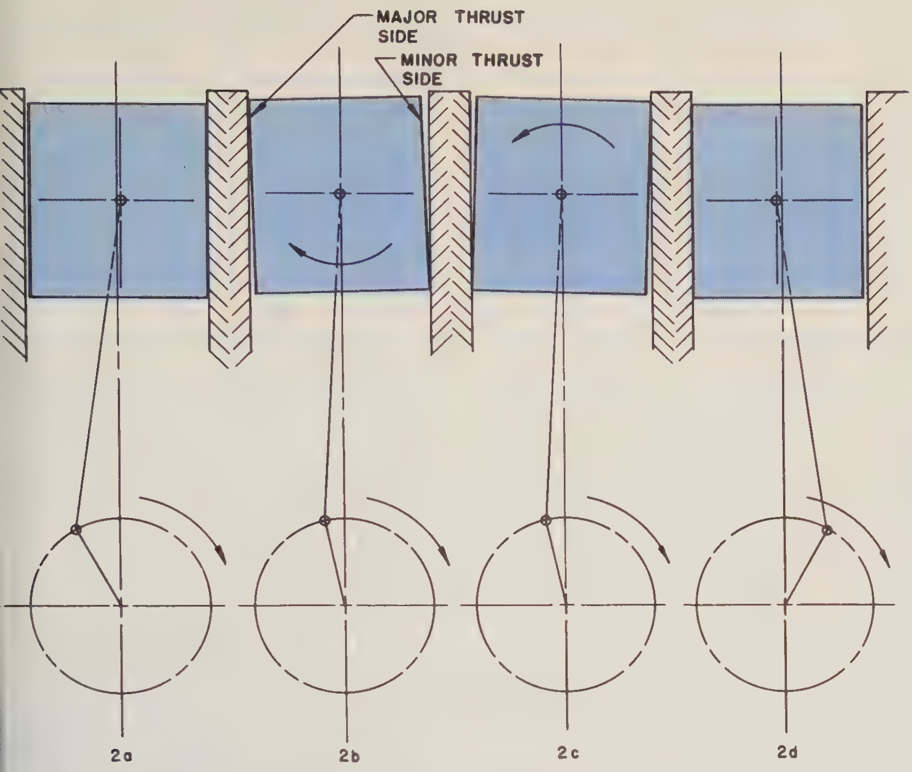


Fig. 2—Four positions of a *cold* piston with respect to cylinder bore and with clearances exaggerated for illustrative purposes. Fig. 2a shows the piston during the up-stroke; note that the minor thrust is against the right side, in the direction of crankshaft rotation. Fig. 2d shows the piston during down-stroke; note that the major thrust is against the left side, in the direction opposite to that of crankshaft rotation. Major thrust occurs during the power stroke. Fig. 2b shows the piston side thrust reversal resulting in audible slap and Fig. 2c shows the piston at the same crankshaft position with side thrust reversal resulting in minimum audible slap. The condition in Fig. 2c is the piston designer's goal. Normally, piston slap is significant only on the power stroke.

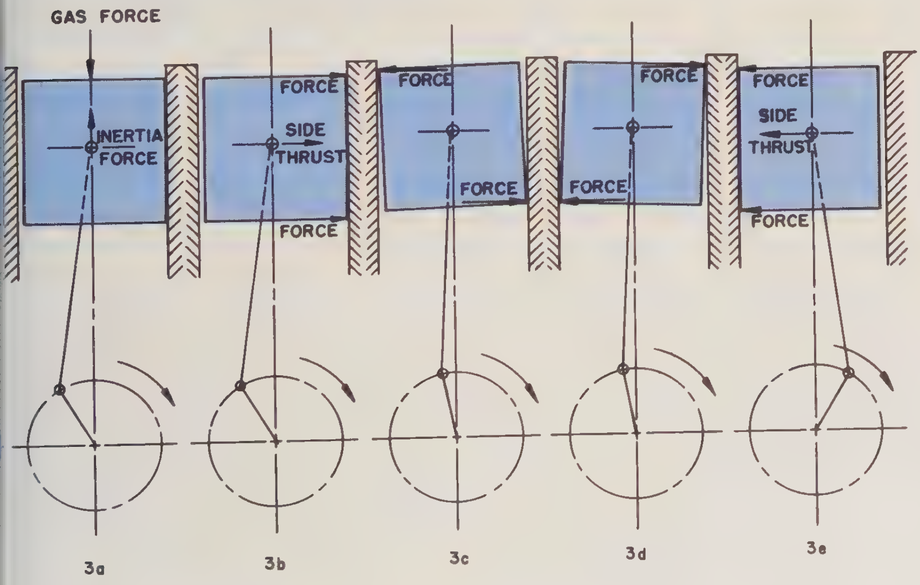


Fig. 3—Five positions of a cold piston with respect to cylinder bore, with clearances exaggerated as in Fig. 2. Fig. 3a indicates inertia force acting upward and gas-pressure force acting downward. Fig. 3b shows the side thrust and the resultant forces at top and bottom of the piston during up-stroke. Fig. 3c shows the undesirable forces causing the top of the piston to reverse before the bottom. In this case, the approaching power stroke causes the bottom of the piston to reverse at high velocity resulting in a slap. In Fig. 3d, the forces produce optimum side thrust reversal. Fig. 3e indicates that during the down-stroke, the forces against the cylinder bore are opposite to the forces during the up-stroke.

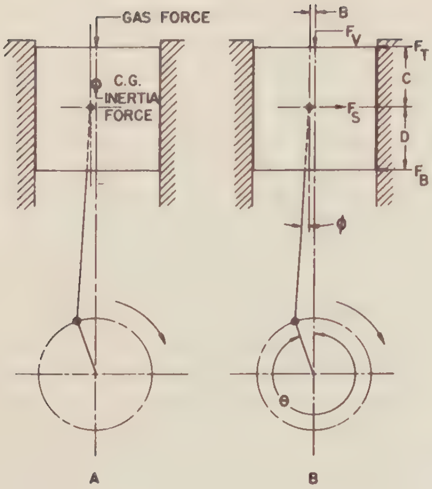


Fig. 4—Representation of forces as used in formulae for mathematical solution.

at a low velocity before the top of the piston, the engine usually is free of audible piston slap. In any given engine, and with a pre-determined piston design, the vertical position of the pin in the piston as well as the lateral position affects the lateral motion of the piston.

The following method of analysis is used to determine the lateral position of the pin which will result in the minimum audible piston slap.

Analysis of Piston Slap Tendency

It is necessary that the designer or engineer consider all the forces affecting the piston when it is near the top of the firing stroke in order to determine slap tendency. During the upstroke, the crankshaft is pushing the piston causing the piston to contact that part of the cylinder wall which is in the direction of the crankshaft rotation (Fig. 2a). During the downstroke, the piston is pushing the crankshaft, so that the piston is in contact with the opposite cylinder wall (Fig. 2d). The key factor affecting slap lies in how the piston movement from one side of the bore to the other takes place. Because resultant side thrust forces on the piston result in rotational tendency, either the top or the bottom of the piston makes the crossing first.

Supposing the top of the piston crosses first. Then the gas-pressure causes the bottom to cross at high velocity tending to produce audible slap. However, if the bottom of the piston crosses first at low velocity, the top can cross at relatively high velocity without audible slap because the piston ring friction tends to impede movement of the top.

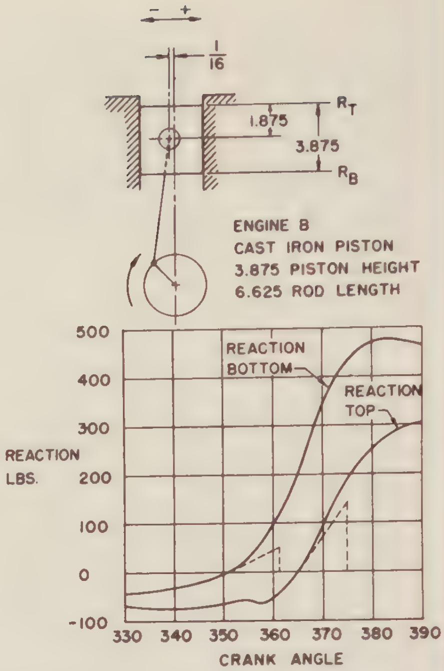


Fig. 5—Graphical result of the solution from Table III showing piston slap tendency with pin located 1/16 in. offset toward the major thrust side. The intersection of the reaction curves with the zero horizontal axis locates the point, with respect to the position of the crank arm, where the reversal of forces occur. The value of the tangent to the curve, as shown by the dotted line and which is used to determine the best pin lateral position, shows the rate of side thrust reversal.

The principal forces involved are the gas force acting on the top of the piston and the inertia force acting at the center of gravity of the piston and ring assembly (Fig. 3a). Because the piston is restrained by the pin and connecting rod, these forces are resolved into side thrust due to connecting rod angularity. In the analysis, the side thrust forces are resolved into forces of a couple acting at the top and bottom of the piston.

Mathematical Analysis

Mathematical solution of the formulae for the forces and couples acting on the piston determine slap characteristics. A graphical plot of the results, using the crank angle as the horizontal scale and force as the vertical scale, plotting force at the top of the piston as one curve and force at the bottom of the piston as th other curve, presents a clear picture o slap tendency. Graphically, determinin the slope of the curve at the point o force reversal on the bottom of the pisto determines the piston slap factor o lateral velocity.

INERTIA FORCES	GAS FORCES
F_i = Inertia Force	F_g = Gas Force $= AP$ where A = Area of bore 11.044663 sq in P = Gas pressure l per sq in. at crank angle (Theoretical indicator diagram computed fo engine speed a which *slap* is be ing studied.)
$F_v = F_i$	$F_v = F_g$
$F_h = F_s$ $= F_i \tan\Phi$	$F_h = F_s$ $= F_g \tan\Phi$
$\Sigma M_o = 0$	$\Sigma M_o = 0$
$F_t = \dfrac{F_i(-2.7747\tan\Phi + 0.0625)}{1.1003 + 2.7747}$	$F_t = \dfrac{F_g(-2.000\tan\Phi + 0.0625}{1.875 + 2.000}$
$b = -0.0625$	$b = -0.0625$
$c = 1.1003$	$c = 1.875$
$d = -2.7747$	$d = -2.000$

Table I—Mathematical values for solution of th example given in the text.

Formulae for Mathematical Analysis

The following formulae are used t solve piston slap problems. As may b noted from the calculations, the ga force is the predominant force affecting slap and for rapidity of solution th inertia forces may be neglected.

Consider the forces symbolically described in Figs. 4 and 5.

$$\Sigma F_v = 0 \quad (1)$$

where

F_v = vertical forces.

$$\Sigma F_h = 0$$

$$F_h = F_s \quad (2)$$

		INERTIA FORCES—lb			GAS FORCES—lb		
Θ	Φ	$F_h = F_i \tan \Phi$	F_t	F_b	$F_h = F_g \tan \Phi$	F_t	F_b
320°	− 9.0518°	−19.65	16.06	3.59	119.12	− 73.54	− 45.58
330°	− 6.9084°	−18.32	15.55	2.77	131.41	− 85.32	− 46.09
340°	− 4.5482°	−13.72	12.61	1.11	120.28	− 86.47	− 33.81
345°	− 3.3085°	−10.42	10.37	0.05	102.16	− 81.23	− 20.93
350°	− 2.0411°	− 6.62	7.73	−1.11	76.76	− 74.35	− 2.41
355°	− 0.7550°	− 2.49	4.84	−2.35	36.53	− 63.57	27.04
360°	0.5405°	1.79	1.78	−3.57	− 50.01	− 59.69	109.70
365°	1.8365°	6.07	1.29	−4.78	−241.51	3.16	238.35
370°	3.1233°	10.14	− 4.26	−5.88	−441.75	97.42	344.33
375°	4.3920°	13.84	− 7.00	−6.84	−628.58	192.42	436.16
380°	5.6335°	17.01	− 9.40	−7.61	−740.72	261.19	479.53
390°	7.9987°	21.24	−12.77	−8.47	−790.57	317.29	473.28
400°	10.1482°	22.08	−13.82	−8.26	−741.35	315.83	425.52

Table II—Analysis of side thrust forces at various points of crankshaft rotation.

Θ	F_T—lb	F_B—lb
320°	− 57.48	− 41.99
330°	− 69.77	− 43.32
340°	− 73.86	− 32.70
345°	− 70.86	− 20.88
350°	− 66.62	− 3.52
355°	− 58.73	24.69
360°	− 57.91	106.13
365°	1.87	233.57
370°	93.16	338.45
375°	185.42	429.32
380°	251.79	471.92
390°	304.52	464.81
400°	302.01	417.26

Table III—Summation of forces for the same points as in Table II. The forces at the bottom of the piston reverse somewhere between 350° and 355° of rotation while the forces at the top reverse about ten degrees later, reducing the audible slap.

where

F_h = horizontal forces

F_s = side thrust

$$F_h = F_v \tan\Phi \qquad (3)$$

where

Φ = angular displacement of connecting rod from vertical $= \sin^{-1}\dfrac{-R \sin \Theta + b}{L}$

in which

R = crank radius

Θ = crank angle

b = piston pin offset

L = connecting rod length.

$$F_h + F_t + F_b = 0 \qquad (4)$$

where

F_t = force at top of piston

F_b = force at bottom of piston.

For either the gas-pressure force or the inertia force, the summation of moments equals zero taken about a fixed point, which is the center of the piston pin in the case of the former and the piston's center of gravity in the case of the latter.

Therefore:

$$\Sigma M_o = 0 \qquad (5)$$

$$F_v b + F_t c + F_b d = 0. \qquad (6)$$

From (4),

$$F_b = -(F_h + F_t).$$

Substituting in (6),

$$F_v b + F_t c - (F_h + F_t)d = 0$$

$$F_t c - F_t d = F_h d - F_v b$$

$$F_t(c - d) = F_h d - F_v b$$

$$F_t = \frac{F_h d - F_v b}{c - d}$$

$$F_t = \frac{dF_v \tan \Phi - F_v b}{c - d}$$

$$F_t = \frac{F_v(d \tan \Phi - b)}{c - d}$$

where

b = piston pin offset

c = distance from center of gravity to top of piston in solving equation (6) for inertia forces and the distance from centerline of piston pin to top of piston in solving the same equation for gas forces

d = distance from center of gravity to bottom of piston in solving equation (6) for inertia forces and the distance from center line of piston pin to bottom of piston in solving same equation for gas forces.

Example

The mathematical solution for an engine is shown in Tables I, II, and III. From these data, it may be seen that the gas force is the predominant force affecting slap and, for rapidity of solution, the inertia forces may be neglected.

A graphical plot of the results shows two curves, Fig. 5, using crank angle as the horizontal scale and force as the vertical scale. One curve is the reaction in pounds between the bottom of the piston and the cylinder wall. The other is the reaction between the top of the piston and the cylinder wall.

The negative portion of the curves shows the forces acting when the piston is forced toward the minor thrust side or during the compression cycle (for illustration of minor thrust side see Figs. 2b and 3b).

The positive portion of the curves shows the forces between the cylinder wall and the piston on the power stroke or when the piston is toward the major thrust side (for illustration of major thrust side see Figs. 2b and 3e).

The point on the horizontal or crank angle scale at which the reaction is zero is the point of side thrust reversal. In the case of Fig. 5, the force reversal occurs at the bottom of the piston before force reversal takes place at the top of the piston—one of the required criteria for reduction of a slap.

Plotted tangents to the curves at the zero line are shown by the dotted line (Fig. 5). Using these tangents as the base for slap tendency, tests show that if the value of the tangent is 0.70, or less, for the bottom of the piston and that its reversal occurs prior to the reversal at the top, the audible piston slap is reduced to a minimum.

Figs. 6 and 7 show the results of analysis for two different rod lengths and for offsets in opposite directions.

Fig. 6 shows graphs of the forces for two engines *A* and *B* affecting side thrust reversal at the top and bottom of the piston when the offset is 1/16 in. toward the minor thrust side of the cylinder. Fig. 7 gives data for the same engines when the offset is 1/16 in. toward the major thrust side of the cylinder.

Summary

With the stroke, rod length, piston design, and height of the pin in the piston pre-determined, the only variable by which piston slap characteristics may be altered is the piston pin offset relative to the centerline of the bore and the piston. It has been found that piston slap becomes inaudible only when the force reversal occurs at a low velocity. By applying fundamental physics, this analytical method successfully predicts the exact pin location to reduce slap resulting in an engine of better design.

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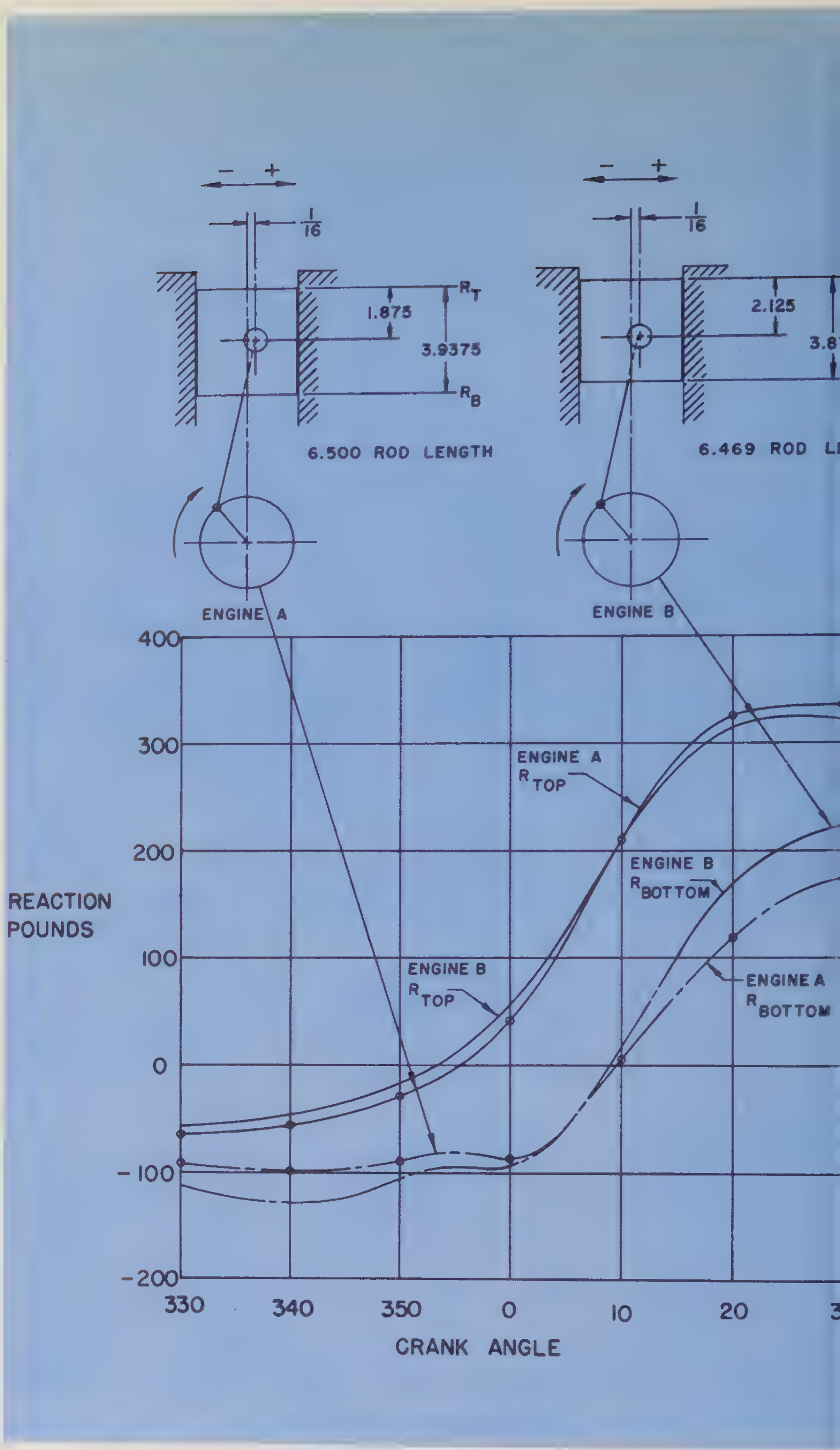

Fig. 6—The effect of locating the piston pin 1/16 in. offset toward the minor thrust side can be observe from these curves. Reversal takes place at the top of the piston ahead of the bottom.

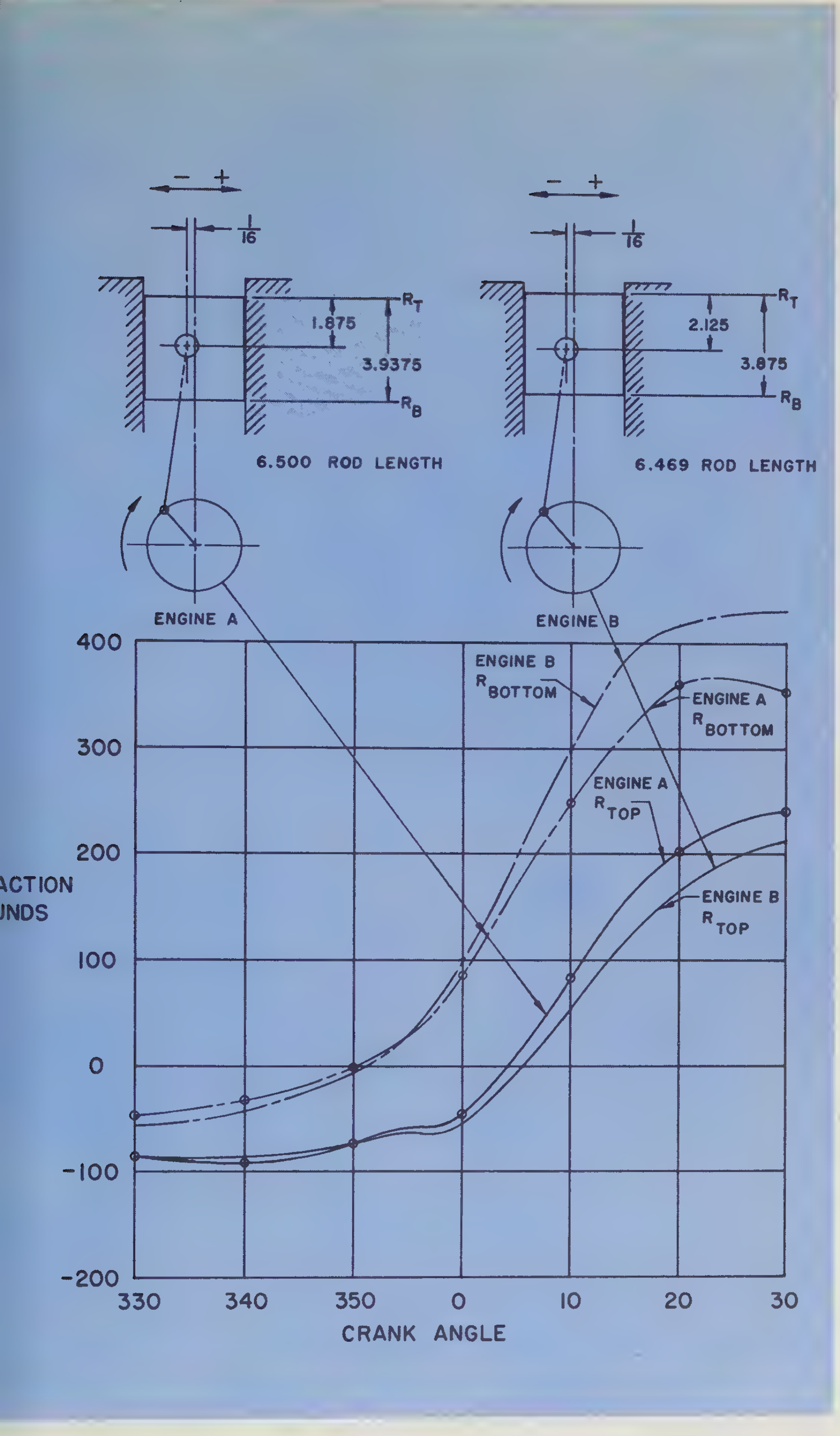

Fig. 7—Contrasting effect of locating the pin the same distance toward the major thrust side of the piston. Reversal occurs first at the bottom.

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A MESSAGE TO ENGINEERING EDUCATORS about the

GENERAL MOTORS Engineering JOURNAL

The General Motors Engineering Journal is now a scheduled every-other-month publication aimed to supplement engineering classroom presentations as engineering faculty members may see fit to use each issue. We hope it always will fulfill its objective of bringing up-to-date information into classrooms through the medium of technical papers prepared by General Motors engineers.

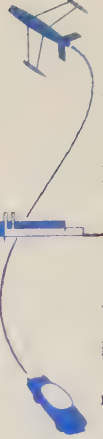
In this and succeeding issues the Journal strives to present material of importance in as many fields of engineering as possible and appropriate to our engineers' work. An index is being prepared and will be published as part of the May-June 1954 issue.

The Journal is distributed on a request basis to engineering educators and, through them, to engineering students. To be placed on the regular mailing list of the Journal address a request to the editor on your institution's letterhead. Requests for additional copies for use by students also may be directed to the editor.

Kenneth A Meade

Kenneth A. Meade,
Secretary, Advisory Board

An Engineering Solution for the Development of a Civilian-Military Factory



By JOSEPH M. NEWMAN
and ROBERT W. ENGLE
B.O.P. Assembly Division
Kansas City

The problem of laying out and tooling a plant to produce automobiles and aircraft simultaneously, yet with the ability to convert quickly to total production of either, has been solved at Buick-Oldsmobile-Pontiac Assembly Division at Kansas City, Kansas. This dual-purpose plant is one which can operate in one of three ways—producing peacetime products, producing defense materiel, or producing both types of goods at the same time while using the same basic core of employes and facilities.

A case study in industrial mobilization

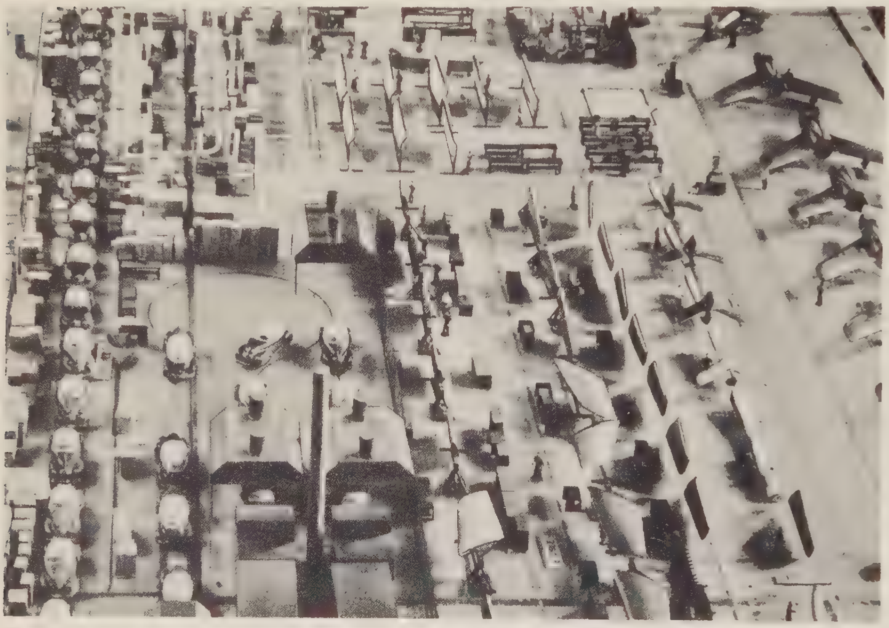


Fig. 1—A portion of the elaborate model used in plant studies is pictured. The model is a 1/48th-size replica of the dual-purpose plant and was used to find a workable arrangement of space and equipment. This three-dimensional plan covers a 664-square foot table and employs scaled machines and aircraft, many of which were designed and built to exact scale by plant engineers.

On October 4, 1951, before the American Ordnance Association, Mr. Charles E. Wilson, then president of General Motors, delivered his policy-making speech, "Preparedness As a Continuing Policy." Mr. Wilson reminded his audience that industrial mobilization for war was usually "met with emergency measures which are exorbitant in cost, disruptive to the civilian economy, and may not be adequate in time."

Mr. Wilson proposed that dual-purpose plants be set up with the flexibility to operate three ways—"for combined production, for total war production, or for total civilian production." Such plants, already in existence and operating with experienced industrial labor, supervision, and management in their normal location could be "quickly and flexibly converted back and forth from one purpose to the other without great expense."

The Kansas City Plant of the Buick-Oldsmobile-Pontiac Assembly Division was soon afterwards directed to rearrange and augment its facilities to produce the Republic F-84F *Thunderstreak* airplane concurrently with the production of automobiles.

One of the most difficult problems involved in the development of the plant for aircraft-automobile production was to select and evacuate areas to be used for the new aircraft production activity.

The automotive operation, which was to be reduced from its normal production capacity by about 40 per cent, was fairly evenly distributed over the 1,475,000 sq ft of the main plant's first-floor area. The immediate problem was how to compress the automotive operation and where to locate the elements of the new aircraft operation.

Many studies were made—perhaps a hundred in all—exploring all plausible combinations of areas and activities. Fig. 1 pictures the scaled machines, racks, and aircraft which constitute the model layout used in the plant studies. As the studies progressed it became more and more apparent that, to properly satisf the dual-plant definition, the layout must be readily expandable into either maximum defense or maximum commercia production with a minimum of disturbance to the level of production before the expansion.

The ultimate selection of the dual-plant layout was based on this principle of ready expandibility of either of the dual activities with a minimum of loss of time and production capacity. Such a layout establishes the principle of placing defense production departments within the plant in such a manner that they can be expanded to their maximum size by growing into adjacent areas which are (during dual operations) occupied by commercial activities (Fig. 2.).

To illustrate a layout solution for a period of 100 per cent defense production, Fig. 3 shows how expansion of existing aircraft units into automotive production areas can be achieved without conflict.

The defense production departments, as they operate under dual-purpose conditions, are referred to as *seed areas*. In Fig. 3 it can be seen that should it be necessary to cease or diminish automotive production, it would be possible for the Aircraft Machine Shop to expand into the Automotive Body and Trim Shop zones without exerting any pressure upon adjoining aircraft areas. The Aircraft Sheet Metal Shop is also able to expand into the Automotive Body, Trim, and Paint Shop zones without conflicting with any adjacent aircraft areas. In a similar fashion, it is possible for the Aircraft Final Assembly area to expand toward the center of the plant without having to rearrange any of the adjacent aircraft areas. It would be possible in most cases actually to leave much of the automotive heavy equipment in place to reduce cost and time of returning to civilian production, when required.

DUAL PURPOSE:

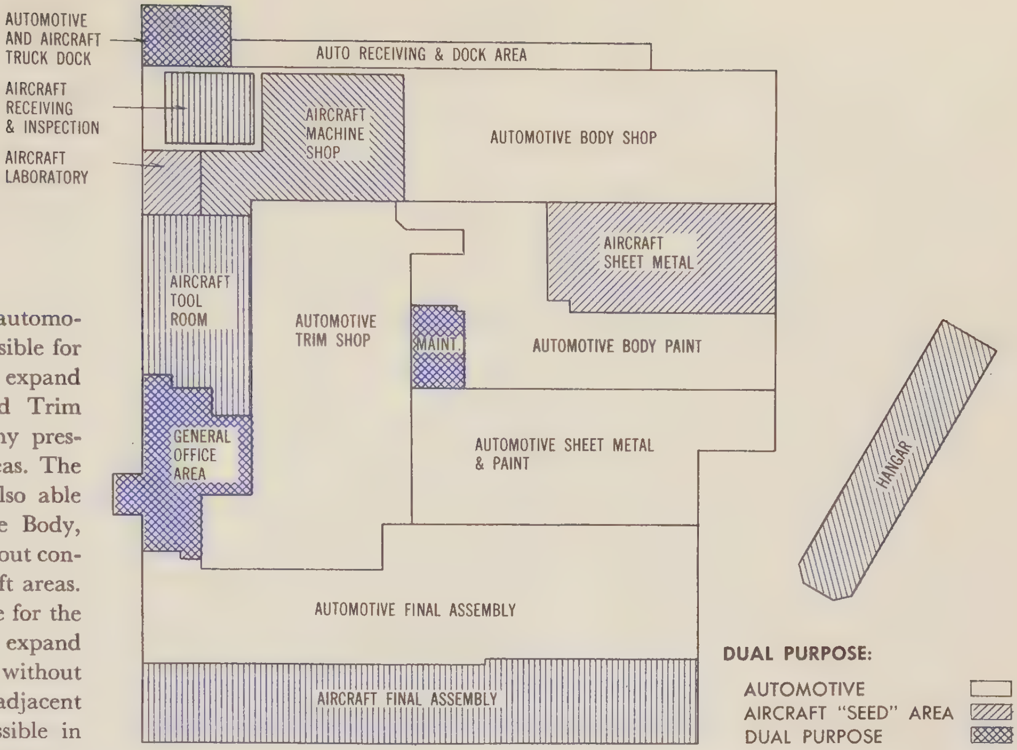


Fig. 2—A typical dual-plant layout illustrating defense departments (with expandable areas) co-existing with commercial operations areas.

100% AIRCRAFT:

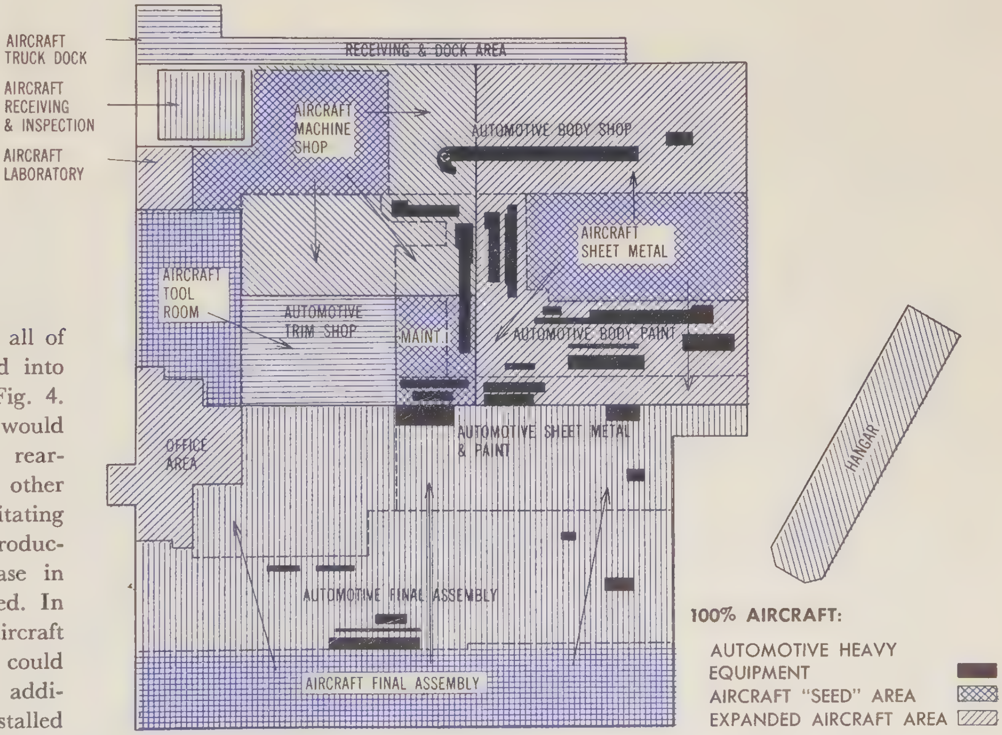


Fig. 3—Layout showing how automotive areas would be taken over by aircraft production facilities under 100 per cent defense production. Note that areas are provided for certain automotive heavy equipment which would remain in place even during all-out defense production.

How different this would be if all of the aircraft areas were combined into one portion of the plant as in Fig. 4. An increased aircraft production would necessitate mass relocations and rearrangements of aircraft areas into other portions of the plant, thus necessitating complete shutdowns of aircraft production activities before any increase in aircraft capacity could be realized. In the other example (Fig. 3), the aircraft seed areas, or basic defense units, could maintain their production while additional facitilites were being installed around their perimeters with little loss of production efficiency.

The formula works equally well for the opposite condition (Fig .5). Assuming that the aircraft program is diminished, or temporarily curtailed, the layouts are so designed that with relatively little rearrangement, the automotive areas can be expanded into adjacent aircraft areas, thus increasing the production potential of the automotive areas. Again this expansion can be performed without any mass relocations, and with little loss of production capacity by the seed areas during their period of expansion. The heavy aircraft equipment would, of course, be left in place on a standby basis to expedite and reduce the cost of an eventual return to defense production if, and when, required.

Having decided on the layout solution which was to be used, the commercial operations were then reduced in order to release the required areas for defense operation. Here, too, the layout solution proved its merit since it was possible to obtain the aircraft areas where needed with a minimum of disturbance to commercial operations.

Actually—because few major relocations of heavy equipment were required—these rearrangements were accomplished with no major loss of production time.

On July 7, 1953, the first jet fighter-bomber manufactured at B.O.P. Kansas City successfully completed its initial test flight from Fairfax Field. Plans are going ahead to complete 1954 schedules as required by the armed forces.

DUAL PURPOSE:

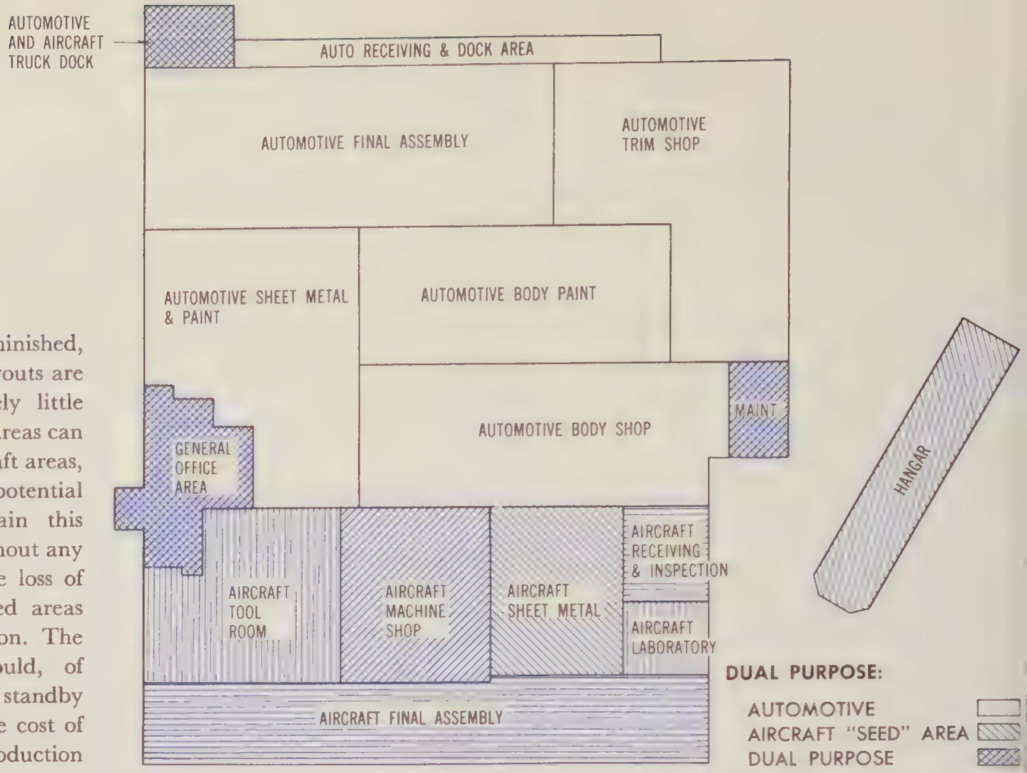


Fig. 4—This layout shows the undesirable condition of combining all aircraft areas in one plant location. Expansion of either type of production requires major plant rearrangements.

100% AUTOMOTIVE:

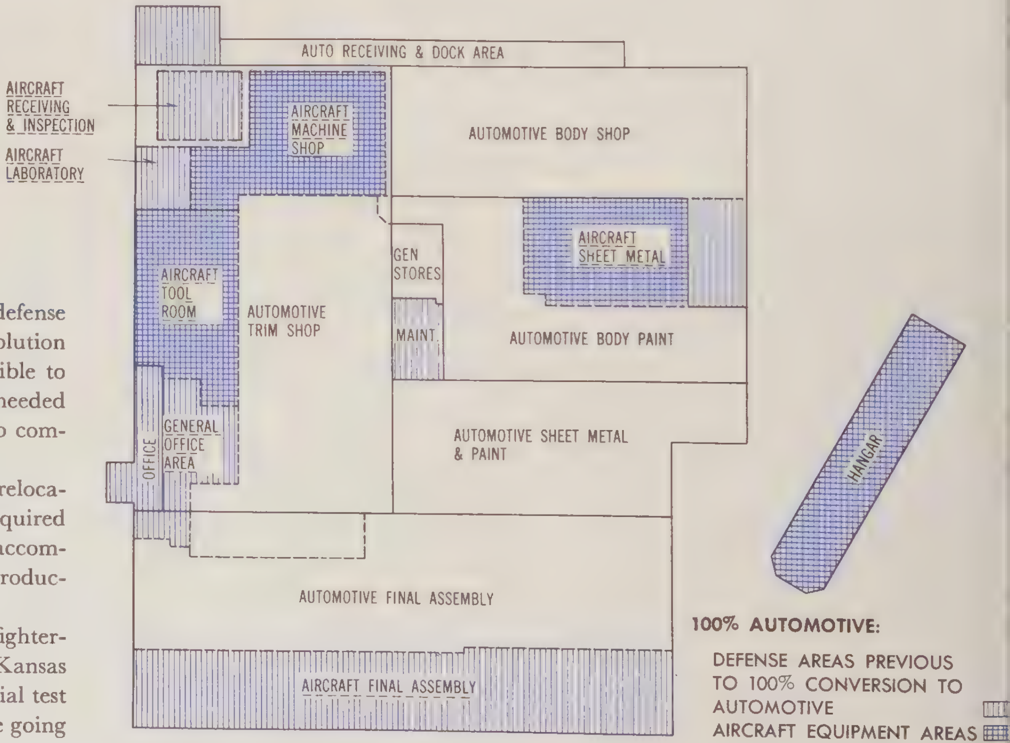


Fig. 5—Dual-plant layout under 100 per cent automotive production. Note that areas are provided for aircraft equipment and re-conversion would be possible on short notice.

Technical, Economic, and Human Factors Affecting the Design and Use of Special Machinery

By ROBERT L. KESSLER
Delco-Remy Division

Combining optimism, ingenuity, cooperation to produce efficient machinery

Progress in mass production of parts has depended heavily through the years on the development of special machinery to simplify and reduce the element of human labor. Special machinery is now drawing toward reality the truly automatic factory, but more is required than machinery alone. The design of a successful machine must take into account a vast range of economic factors during every step from conception through the initial period of production with the new machine. Not all of the necessary ingredients relate to technical knowledge; rather the technical ability to develop a new machine must be related to human and economic factors if the machine is to be successful.

IN INDUSTRY, the term *special machinery* usually means any piece of equipment which, because nothing is available on the commercial market, must be specially constructed for performing one or more operations on a product. Such a machine may be completely new or it may be converted from a standard machine like a punch press or a milling machine so that, in effect, it becomes a special machine.

Special machines have come into wide use because they provide another way to reduce costs in the manufacturing plant. The savings occur not only in the operation performed by the machine itself but very frequently they also occur in materials, perishable tools, or other operations affected by the machine. Special machines also contribute to improved quality, reduced worker fatigue, and elimination of safety hazards. There are many limitations which affect the design of such machines, however. Such considerations as cost of utilities, plant overhead, effect upon other operations, and difficulty of maintenance may wipe out any savings expected from the new machine. The design of special machines, therefore, is a complex procedure involving many considerations quite apart from the engineering features. No longer is the single effort of the "mechanical genius"—admittedly effective in some designs—applicable in a large proportion of the work today. Instead, many companies utilize their own organizations of specialists in different fields who coordinate their efforts in developing satisfactory machines. More than 1,100 special machines, ranging from coil winders to assembling machines (Fig. 1) have been designed, built, and put in use at the Anderson, Indiana plants of the Delco-Remy Division.

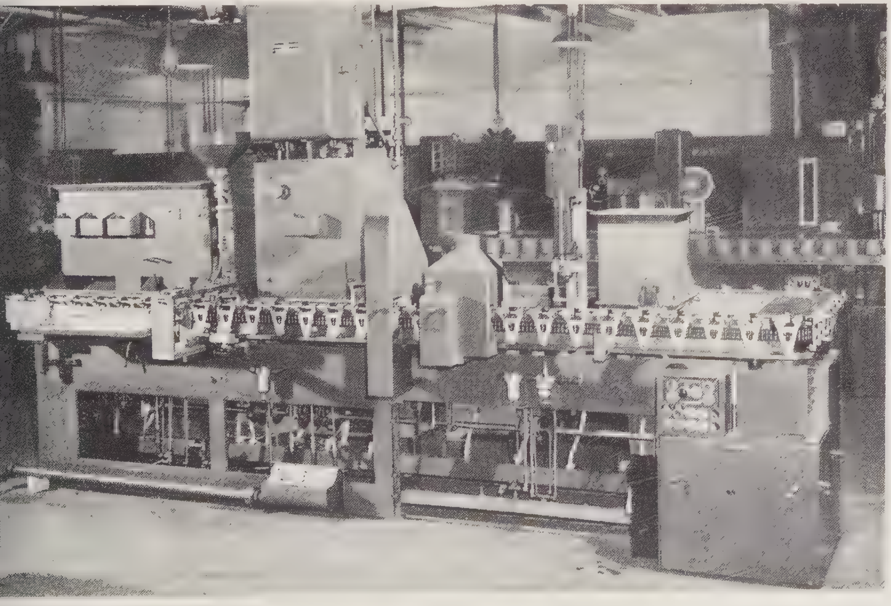


Fig. 1—This in-line indexing machine is employed in the assembly of distributor levers. This type of machine may be fitted with special attachments for welding, riveting, or machining as well as automatic feeding devices for small parts. Automatic inspection stations also may be included.

The Human Factor

Before discussing the actual procedure at Delco-Remy, it is appropriate to consider three important conditions which must be present before the design and construction of special machinery may be undertaken.

The first of these involves management. Only an optimistic and patient management risks making the initial investment in special machinery and relies on its organization to improve the many flaws in newly-created machinery. The building of special machinery is a venture which requires strong and courageous guidance by management to achieve crystallization of creative effort.

A second condition is the availability of skilled tool and maintenance help. The progress and applications made in recent years in the fields of hydraulics and electronics have made imperative the availability of skilled labor for successful maintenance of special machines.

The third condition concerns the cooperation of production supervisors in both the preliminary planning and the actual operation of the new machines. Every effort is made to convince production supervisors that their interests are being considered and that they are important members of the team. They need to be convinced that the success or failure of special equipment to a large

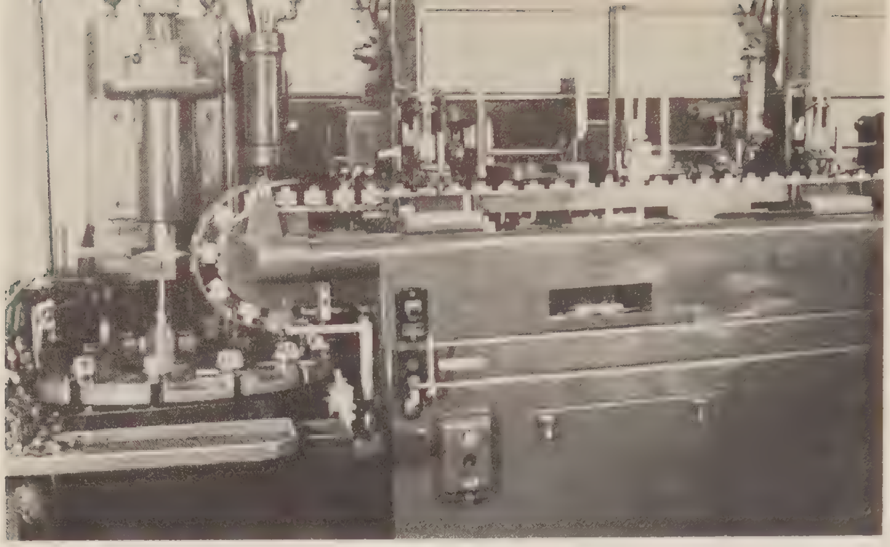


Fig. 2—This assembly operation of automotive-type condensers adapts methods observed by Delco-Remy engineers in use in manufacturing a different product in another plant. Ideas for special machines often originate from sources such as this as well as from product changes and employe suggestions.

degree is a reflection of their supervisory ability.

Conception of New Method

The original idea to employ a new machine may have a variety of sources. If the profit situation on a particular product is unfavorable, an analysis of the present production methods frequently produces ideas for a more efficient tooling approach. Newly-designed products and engineering changes in the design of present products often develop the need for special machinery. Suggestions from top management, from members of some section committee such as Delco-Remy's Production Engineering Group, or from hourly-rated employes may result in special machinery to accompany new processes, promote safety, reduce costs, or promote efficiency (Fig. 2).

Analysis of Factors

Screening out special machinery ideas which are economically impractical requires an extremely accurate analysis of the many factors involved. If estimated labor savings and equipment costs appear favorable, a detailed analysis is made covering all other factors which may influence the final decision. Representatives from production supervision, product engineering, plant engineering, tool and machine building supervision, machine design, and cost accounting analyze the following considerations to determine the value of the proposed special machinery:

- *Actual present production rate* is checked for optimum performance under the present method before comparing with the proposed method.
- *Production rate and number of machines required* for the new method of operation are considerations which help determine the value of employing special machinery. If the production rate of the proposed machine is fixed by the rate of a balanced line, there is no value in producing more pieces than are fed to it by preceding machines or can be used by subsequent machines. If the machine is not in a balanced lineup, the production rate is determined by the cost of the equipment. If multiple machines are required, it is possible to operate more than one per operator, and this may be profitable even though the productive rate per machine is lowered (Fig. 3). Very expensive machines may be operated more hours per day to keep down the number of units required.
- *Maximum production required in comparison to the number of daily hours or work shifts available* to maintain this schedule is an important relationship.
- *Cost of the special machine* is estimated, taking into consideration design, construction, and elimination of initial failures. The cost of the latter, the most difficult part of the estimate, may run from 10 per cent to 100 per cent over the original cost of building the machine. Twenty per cent is a fair average figure.
- *The length of time in which the model will remain in production* is an indication of whether or not the cost of the equipment may be amortized before it is obsolete.
- *Changes in the model made at the time of retooling* are studied by the Sales and Engineering Departments. Very often, such changes improve the quality of the product and add to the prospective savings.
- *Adaptability of the machine to future model changes* is an important consideration to avoid making expensive production facilities obsolete because of minor product design changes. On the other hand, if there is complete assurance that no changes are contemplated over a long period, the cost of the machine is kept lower by not making it adaptable for other uses.
- *The labor factor* influences the potential saving figure, since the caliber of operator or degree of skill required determines the hourly rate to be paid.
- *Changes required in preceding or subsequent operations* may either affect the saving adversely or lead to further cost reduction (Fig. 4).
- *Changes in plant layout, ventilation, and utilities distribution* are considered in calculating return on investment. The costs of installation, conveyors, ventilation, improved facilities such as transformer capacity, power, air, gas, and water lines are important factors in estimating the value of a new machine.
- *The salvage value* of replaced equipment may be credited to the savings resulting from the new method.
- *Material cost* may nullify other savings if a greater supply or more costly material is required per piece for the successful performance of the proposed equipment.
- *The percentage of rejects*, or cost of scrap parts, is charged against the saving.
- *Additional outlays for plant overhead* may lessen the value of employing a new machine in the following way:

  (a) Perishable tools and non-productive materials required by the new method may nullify the saving effected by the special machine. On the other hand, the new method may decrease the cost of such materials.

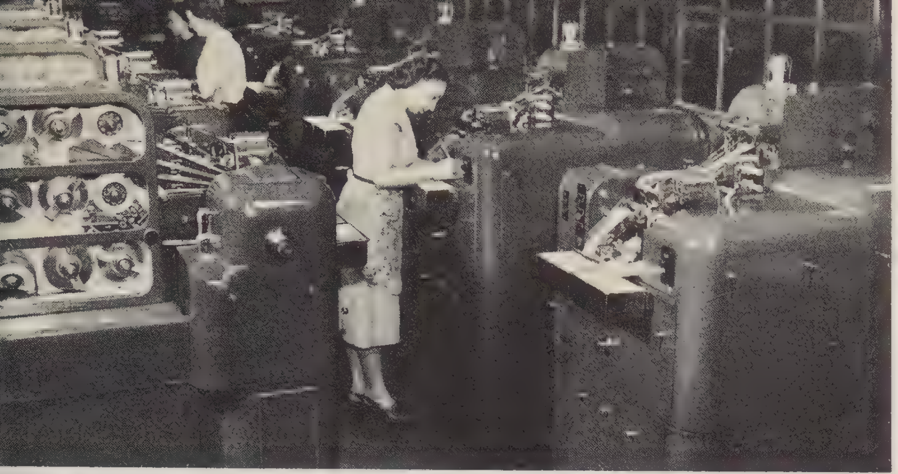


Fig. 3—Automatic condenser winding machines wind alternate layers of aluminum foil and paper, cut off, and apply adhesive to secure the winding. Three operators look after a group of these machines with ease.

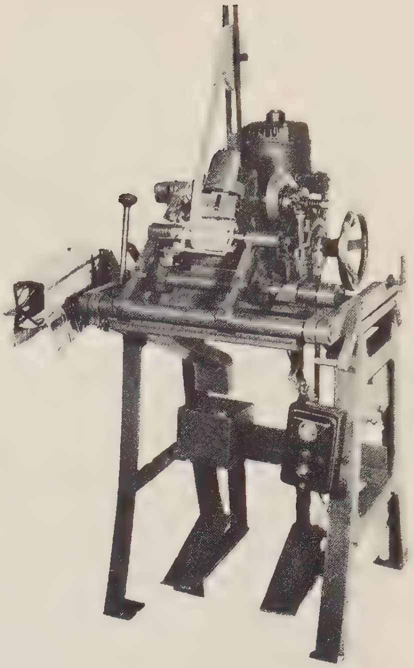


Fig. 4—The use of special automatic lead-connecting machines improved the notching operation on commutators in the manufacture of automotive generators. In addition to satisfying the performance requirements, the design enabled the cost of the machine to be recovered in 18 months. ▶

(b) The cost of utilities, such as power, steam, gas, and air are frequently important considerations in the cost of operation. An air blast device to eject heavy pieces may cost as much as hand labor to unload a machine.

(c) The cost of machine and tool maintenance, on the average, increases with an increase in equipment complexity. It may temporarily decrease due to the relative age of the old and new machines, but the average over the life of the equipment should be considered.

(d) Provisions for alterations in insurance, depreciation, and tax charges resulting from the new capital investment are considered in cost estimates.

(e) The plant overhead increases if the machine is built on a labor saving basis. The lower labor cost, against which all other costs are pro-rated, causes an increase in percentage overhead.

It is important to recognize that the basis for replacing existing machines with special machines is not always confined to cost comparisons alone.

Frequently there may not be sufficient savings to justify complete replacement. It becomes obvious, therefore, that the best which can be done for consideration of such special equipment is in the tooling of a new product when it then may be only necessary to justify with saving the difference in cost between standard equipment and the special machines desired.

Thus, in many cases, it is economical to provide single purpose special equipment in the original facilities where it would not be economical as a replacement.

Design Selection

If, upon evaluation of the above factors, the proposed special machinery appears to be a worthwhile investment, the stage is set for actual design layouts. Since the most economical place in which to correct mistakes in special machinery is on the drawing board, the ideal time for the first design conference is after the first rough layouts are made. A skilled conference leader brings out all the basic faults of the design and convinces the designer of the long-term advantages of modifying or possibly beginning anew at this stage rather than having to dispose of an actual machine or parts at a later date. At this early meeting, production supervisors become well-acquainted with the proposed equipment. Participating in the design stage helps them recognize that the machine is being built to help them rather than being forced upon them. Gaining acceptance in an organization's lower echelons is as important as obtaining favorable top-management decisions.

Design at Delco-Remy is planned largely to suit basic operations available through the common manufacturing methods which can be tooled and adapted with minimum effort. Factors which influence selection of design and which play a vital role in successful operation of special equipment are the following:

- Analysis of required motions and their sequence to establish the minimum possible cycle time
- Decision on the type of machine which can best accommodate the movements and sequence
- Analysis of the forces required to be transmitted by the movements as well as feeds and speeds
- A choice between mechanical, hydraulic, air, and electrical means for supplying these forces
- Thorough dissection of the layout of the machine in the design conference, which includes everyone who will have any responsible connection with the use of the equipment.

In addition to the preceding factors, the following items are discussed in the design conference:

- *Parts subjected to wear* should be designed so that they have adjustments, are readily replaceable, and are inexpensive.
- *Lubrication*, if ignored until a special machine is completely assembled, often proves ineffective and requires expensive design changes.
- *Desirable controls* are those operated with minimum effort.
- *Safety devices*, such as adequate guards and feeding devices, should be

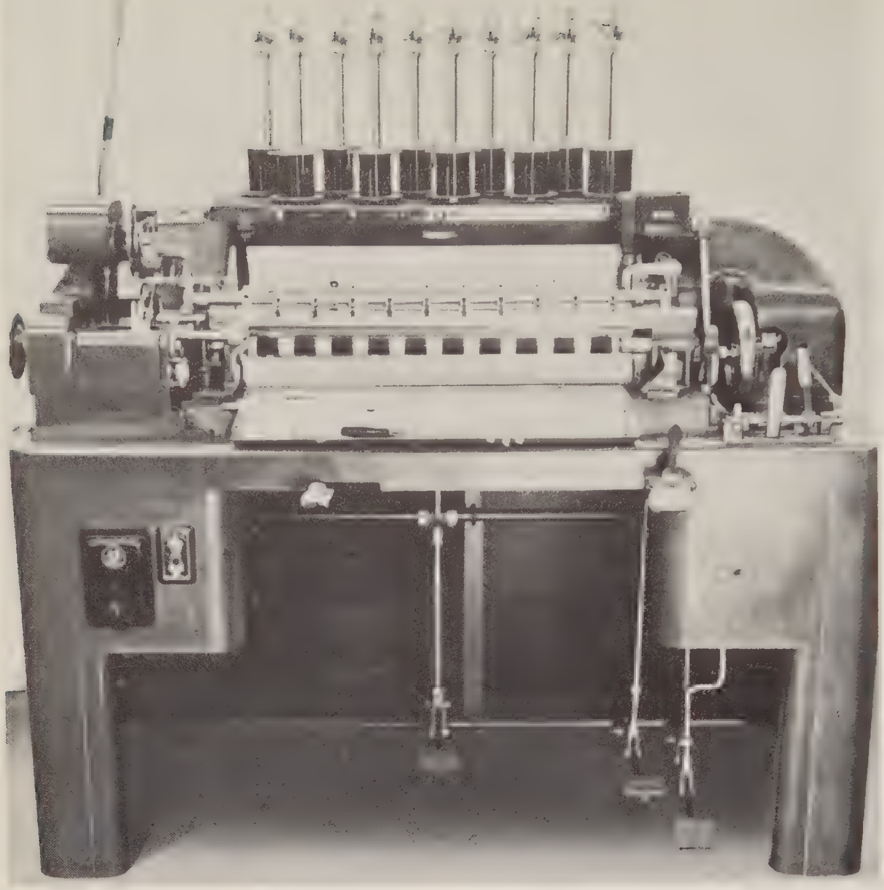


Fig. 5—Forty-eight special machines, built 12 years ago, received considerable emphasis on streamlining. A typical machine of that group, it still presents a fine appearance and has required less than average maintenance.

provided to protect the operator. Built-in safeties to protect the machine against overloading and improper sequencing prevents many costly breakdowns. Too many safety devices, however, may be a source of trouble.

- *The comfort of the operator*, his duties, and the controls he operates affect his satisfaction with the machine.
- *An attractive machine* requires little additional outlay, and this expense is regained through lower maintenance. Heavy guards with smooth contours and floor-length panels dress up a machine and protect the working parts. Flimsy guards are soon out of shape, ill-fitting, and detract from rather than improve the appearance of the equipment (Fig. 5).
- *Simple proven mechanisms* usually can be combined to produce any movement required in a special machine and they are preferred over trick devices. If all of the mechanisms are in successful use in the plant on other equipment, they offer advance proof of satisfactory service and familiarity to tool and maintenance personnel.
- *Provision for moving the machine* is an important part of the design. The designer should provide eyebolts and prying lugs so that the machine is not damaged in handling.

Not to be overlooked in the planning of special equipment is the accurate analysis of the manual part of the operation and the effect it has on the economics of special machinery. In some cases, there may be certain portions of the manual part of an operation which can be economically reduced or even eliminated. It is possible, on the other hand, that some other portions of the manual part of the operations can be better included as manual operations on the special equipment. Designers must guard against the tendency to perform the entire operation mechanically when it could be done much better manually. A wide background in methods training and an understanding of the human part of the job aids in the recognition of this important factor, which should not be subordinated to mechanical problems.

Cost Estimates

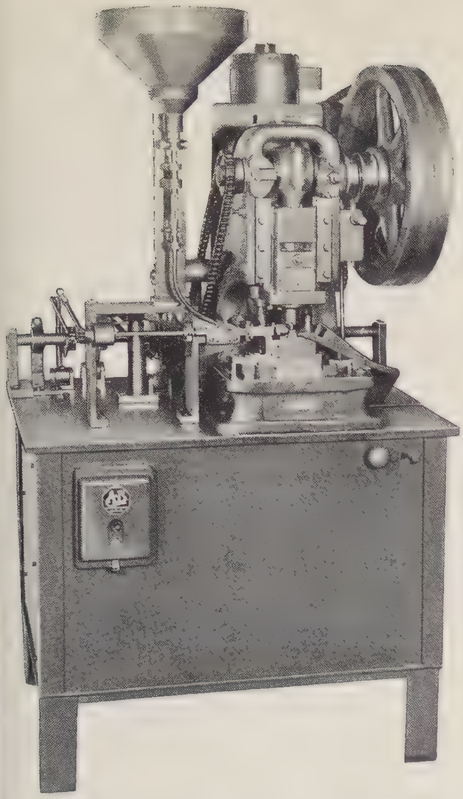
After each of the above factors has been taken into account in regard to the proposed machine and the design layouts have been approved, enough detailing work has been accomplished to permit a fairly accurate estimate of the machine cost. The project engineer prepares a project report which covers the present and proposed methods, estimated cost of new equipment, estimated savings, and investment return. Requests are then made for appropriation approval in order to start actual machine construction.

Construction

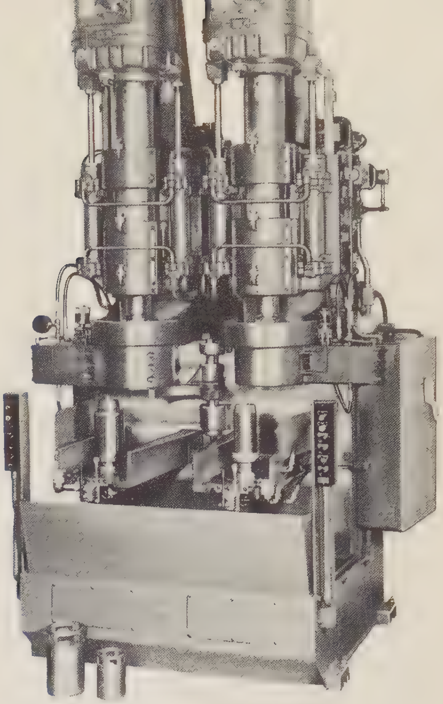
The designer and machine-building shop work closely together in the construction of special machinery, and the shop is given a free hand to make whatever changes are necessary in order to produce a successfully operating machine. Making the machine work requires the highest order of ingenuity and patience, and, as mentioned above, the expense during this early period of correcting flaws may be as much as the entire original cost of the machine. Two dangers exist at this stage: first, the tendency to make radical changes in the machine, and second, an unwillingness to make changes that are actually necessary. Experience and sound judgment are the only guides. Making modifications on a complicated machine often extends over a considerable period, but very seldom does a skilled development organization build a special machine which fails completely.

Machine in Operation

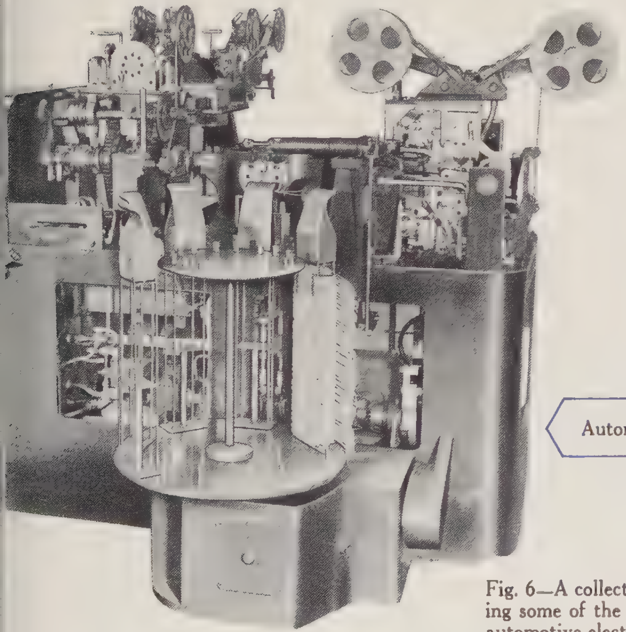
When the machine begins to perform with reasonable success, the project's control shifts from the builder to the operator trainer who starts untrained operators on the machine. The operator trainer, who is interested in the machine as a means of producing so many parts per hour, must understand people and their movements as well as the machine builder understands the machine and its movements. Production supervisors and time study specialists work closely with the trainer, so that the job may be moved into production and produce at an agreed rate when it is ready. A skillful operator trainer—who is invaluable in a special machine organization—moves a new



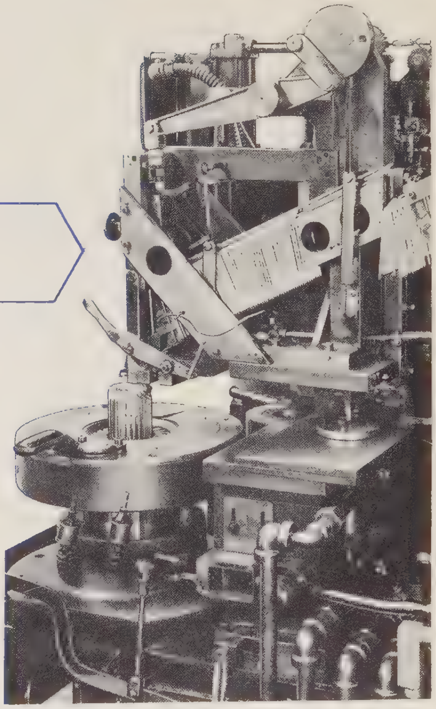
Automatic machine to form loops on ends of coil springs.



Boring machine for motor and generator frames.



Automatic coil winding machine.



Machine to gather and assemble conductors in motor armatures.

Fig. 6—A collection of special machines illustrating some of the types used in the production of automotive electrical equipment.

machine into the production line in the shortest possible time.

Within a reasonable time after the machine is placed into the production setup, its performance record is checked to see if originally estimated efficiencies have been achieved. This performance is as complete in detail as the original cost estimate with which it is compared. Any variations from expected performance are studied and recorded for use on future designs.

A collection of various types of special machines is shown in Fig. 6.

Conclusion

The advent and progress of materials such as tungsten carbide and alloy steels, and the improvements in bearings, hydraulics, and electronics have led to the formation of development organizations, such as Delco-Remy's, where specialists in their respective fields are called upon to assist in proper design of special equipment. The more complete the knowledge of modern arts and facilities that is embodied in this group and the better the understanding of all the problems, the greater the assurance that the special machine will be the best for the job.

Notes About Inventions and Inventors

By GEORGE N. SHAMPO
Patent Section
Central Office Staff

Everything worth inventing has been invented? Not so, records prove

Engineering students and seasoned engineers alike share a stake in the United States patent system. Apart from the general stimulus to invention provided by the patent system, the value of an individual engineering development may be materially reduced without the protection afforded by a patent. From a commercial standpoint, therefore, it is apparent that engineering practices and patent practices are complementary.

Patents have been discussed in two earlier issues of the General Motors Engineering Journal (June-July and September-October 1953 issues). It will be noted from these writings that a patent may be considered as a contract between the granting government and the inventor. Under this contract, the inventor, in consideration for disclosing his invention to the public rather than keeping it a secret, is granted the Constitutionally guaranteed right to exclude others from practicing his invention for a specified number of years.

Also, it has been pointed out previously that the claims in a patent define the extent of this short-term protection by reciting the essential elements of the invention and the interrelation of these elements. Inasmuch as the value of a patent is dependent to a considerable extent on the scope of its claims, it is highly desirable that the patent application contain claims which will afford maximum protection and which, under subsequent judicial scrutiny, are susceptible to the broadest possible interpretation consistent with validity.

With this practical objective in mind, it is of primary importance that the inventor, prior to filing a patent application, strive to foresee how a potential infringer might avail himself of some or all the advantages of the invention by merely modifying it without altering its basic principles. The inventor is then in a sound position to most expeditiously devote his efforts to blocking these avenues of escape from the patent so as to secure the most effective protection of his invention.

Many mechanical inventions are of such a nature that the possible variations can be readily foreseen from examination of the inventive article, but this is not true of all inventions, particularly those of a chemical nature. In the latter instances, the possibility of valid generalization or induction is considerably more restricted, and to obtain proper patent protection it is of the utmost importance that the inventor and his patent attorney cooperate in the active exploration of the possibilities of infringement. This type of invention perhaps may be regarded as commercially incomplete if this exploration is not undertaken. Until the desired degree of legal completeness of invention is attained, the results of technological work are not adequately protected. Under business circumstances which dictate the necessity or desirability of obtaining a strong patent, such a study may well be justified, even though special experimental work may be required for the sole purpose of preparing the patent application.

Apart from the rather unusual situation in which the infringer manufactures or uses an exact duplicate of the invention, three types of actual or potential infringement are possible in which the infringer modifies the invention to a certain extent.

In the first type, the basic idea embodied in the invention may be adopted and a real improvement made. An improvement of this nature may well constitute an infringement and yet be patentable. In such an instance not only does the second patentee infringe the earlier patent but the first patentee is likewise precluded from practicing the patented improvement. The result is a deadlock which terminates only upon the expiration of one of the patents or upon one of the patentees being granted a license by the other. Hence, prior to and during the preparation of a patent application, it is highly advantageous to pursue and extrapolate the inventive idea to the greatest possible extent to forestall the patentability of such inventions by others.

Secondly, an alternative idea may be developed by another. Such alternatives are often employed, particularly when independent inventors have been attempting to solve the same problems by somewhat different methods. If the first inventor is fully cognizant of the breadth of his invention, he frequently can obtain a patent which will cover the subsequently developed alternatives. Apart from independent inventions, of course, competitive manufacturers will almost invariably attempt to evolve a solution which will not be tributary to the patent.

The *doctrine of equivalents*, the principle of law that a patent claim covers that which at the time of the patent grant was considered as equivalent by those skilled in the particular field to which the invention pertains, is not so inclusive as to afford very complete protection for the patentee. Inasmuch as a great deal of reliance cannot therefore be placed on this doctrine, it is advisable for the inventor to devote his attention to foreseeing possible equivalents and verifying the results of their use. Of course, although the inventor is usually fully prepared to study possible improvements because of their technical value, he is frequently reluctant to devote time to the untried alternatives which may be no better than the initially developed embodiment of this invention which possesses proved practicality. Nevertheless, this type of somewhat extended investigation may be necessary if the resultant patent is to provide an effective protection.

Thirdly, the potential infringer of the patent may attempt an evasion which unlike the improvement or alternative, is of no technical importance and actually may be a step backward in the art. Frequently a closely related but somewhat inferior article or process is used in the hope that it will be regarded as outside the patent. In other instances, the potential infringer will rely on some ambiguity of claim terminology and utilize the inventive concept in a manner such that it is verbally not covered by the patent.

These evasions frequently can be prevented if the inventor can devote the time necessary to ascertain the possible variations of his invention, even though these variations may involve a technological retrogression which sacrifices some of the advantages of the invention. The inventor usually can foresee these possibilities and should therefore determine the inventive scope in which the relevant advantages may be partially as well as fully obtained. In other words, while the inventor should determine optimum conditions for technological purposes, it also may be advantageous from a legal standpoint for him to establish the degree to which he can depart from the optimum and yet obtain a result which is novel and useful even to a limited extent.

In order for an inventor to effectively pursue the course outlined above, it is necessary for him to be generally familiar with the existing state of public knowledge as shown by prior patents, other publications, and industrial use. It is also desirable for the inventor to ascertain and inform his attorney of the theory underlying his invention or, in the case of a chemical patent, the mechanism of the reaction. This information is valuable in the mental analysis of the invention and in the appraisal of the prior art even though it may not be included in the patent specification. If no principle is formulated, frequently only that which has been tested by experiment may be satisfactorily protected. Of course, all experimental data, including negative results, obtained by the inventor should always be borne in mind when establishing the breadth of an invention.

Lastly, it is advisable to view the invention in the light of a forecast or program of future activity in the field to which the invention relates. A patent application need not be confined to fully developed inventions but may encompass developments not yet perfected. An anticipation of future developments is therefore an invaluable aid to recognition of the most worthwhile type of patent coverage.

Summarizing, it is the state of the art, the theory of the invention, possible future developments, and experimental results which must be considered in determining both the scope of an invention and the best methods of protecting it against potential infringers who might otherwise avail themselves of the aforementioned devices of improvements, alternatives, and evasions to circumvent the patent. These factors are all interrelated, of course, and each is important in evaluating the others. Without the above information, it is difficult to synthesize a guiding principle which will permit foreseeability of various possibilities of potential infringement as well as the proper demarcation of the invention.

On this and the following pages are listed some of the patents granted during the period from July 1 to September 1. The brief patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each patent.

- **Clovis W. Lincoln, Philip B. Zeigler, Joseph J. Verbrugge,** *and* **John F. Sloan,** *Saginaw Steering Gear Division, Saginaw, Michigan, for a Direction Signal Switch, No. 2,643,308, issued June 23.* This invention relates to direction signal switch mechanisms of the type adapted for disposition in concentric relation with the steering column of a vehicle. A principal feature of the invention is the provision of a slidably and pivotally mounted operating member which not only reduces the tendency of such mechanisms to overtravel but also permits over-riding a manually retained signal without damage to the mechanism.

Mr. Lincoln is chief engineer at Saginaw Steering Gear. He was originally employed by General Motors in October 1932 as a tool and machine designer at this Division. Mr. Lincoln received the B. S. degree in 1915 from University of Illinois. He is a member of Tau Beta Pi and the Governing Board of Mid-Michigan Section of the Society of Automotive Engineers.

Mr. Zeigler serves as assistant chief engineer in the Product Engineering Department of Saginaw Steering Gear. After earning the B. S. degree in engineering from Purdue University in 1941, he was employed by General Motors in June of the same year as a time study engineer at this Division. He is a member of the program committee of the Mid-Michigan Section of the Society of Automotive Engineers.

Mr. Verbrugge is project engineer in the Product Engineering Department at Saginaw Steering Gear. He was originally employed by General Motors in October 1936 as a drill press operator at this Division. Mr. Verbrugge graduated from General Motors Institute in 1941. He is currently engaged with forward development in power steering. Mr. Verbrugge's technical affiliations include membership in the Society of Automotive Engineers.

Mr. Sloan is no longer with the Division.

- **Mark H. Frank,** *Pontiac Motor Division, Pontiac, Michigan, for a Transmission and Control, No. 2,645,135, issued July 14.* The invention relates to improvements in automatic transmissions and controls therefor. An over-running reaction brake replaces the front planetary gearing unit band of the Hydra-Matic transmission for smoother shifting and simplification of the front unit clutch control. A driver operable control is provided to prevent free wheeling when such operation is desired.

Mr. Frank has served as motor engineer in the Engineering Department of Pontiac Motor since October 1942. He has been with the Division since receiving the B.S.M.E. degree from Michigan State College in 1927. Originally employed in the Service Department of Pontiac Motor, he was transferred to the Engineering Department in October 1927. Mr. Frank is a member of Tau Beta Pi, Scabbard and Blade, the Engineering Society of Detroit, and the GM Standards Committee.

- **Milton J. Diamond,** *Central Foundry Division, Saginaw, Michigan, for an Electronic Hardness Sorter, No. 2,647,628, issued August 4.* The invention disclosed in this patent relates to a device for testing the hardness of metal parts by magnetizing the part and then causing it to induce an electrical signal whose strength will be proportional to the hardness of the part, and classifying means actuated by this signal are also included.

- **Milton J. Diamond,** *Central Foundry Division, Saginaw, Michigan, for an Amplifying and Triggering Means for Magnetic Hardness Testers, No. 2,645,341, issued July 14.* The invention disclosed in this patent relates to a modified system of the same form of the above magnetic hardness tester. Two separate pickups and amplifying and control circuits actuated thereby are used for classifying parts on the basis of hardness.

These patent descriptions are informative only and are not intended to define the coverage which is determined by the claims of each one.

Mr. Diamond is research engineer at Central Foundry. He earned the B.S.E.E. degree from University of Detroit in 1932. He was originally employed by GM in January 1936 as an electrician and was promoted to engineer in the Defiance, Ohio plant project in May 1947 and to research engineer in November 1950. Mr. Diamond's previous projects include work in shell molding and electronic hardness testing.

- **Edward F. Weller, Jr.** and **Richard G. Doyen**, *Research Laboratories Division, Detroit, Michigan, and AC Spark Plug Division, Milwaukee, Wisconsin, respectively, for a Constant Amplitude Sweep Generator, No. 2,645,715, issued July 14.* This is a constant amplitude sweep generator having means for synchronizing the sweep frequency with engine speed. Only about half as many vacuum tubes are required as are required in other circuits of this type; therefore the power consumption of this device is much less than in similar devices used in the past. The sweep generator is particularly adapted for use in making road tests of ignition or detonation characteristics.

Mr. Weller has served as assistant head of the Physics and Instrumentation Department of the Research Laboratories since December 1952. He was originally employed as a junior research engineer in this same Department in September 1946. Mr. Weller holds the electrical engineering degree from University of Cincinnati where he was elected to Eta Kappa Nu. This is the first patent resulting from his work. He has authored a paper dealing with a new mixture ratio analyzer.

Mr. Doyen is senior project engineer at AC Spark Plug. He received the B.S.E.E. degree from Iowa State College in 1947. In September of the same year, Mr. Doyen was employed as a junior engineer in the Physics and Instrumentation Department of the Research Laboratories Division. In November 1948 he was transferred to his present position with AC Spark Plug where he is in charge of the electronic product engineering on a bombing-navigational computer for the Air Force. Mr. Doyen is a member of Tau Beta Pi, Phi Kappa Phi, Eta Kappa Nu, and Pi Mu Epsilon.

- **Ralph Altson**, *Hyatt Bearings Division, Harrison, New Jersey, for a Railroad Journal Box, No. 2,646,320, issued July 21.* This patent involves a roller bearing journal box having barriers which prevent surging oil from building up at the rear seal and which drain surplus oil from the bearings toward the sides of the box, thus eliminating oil leakage around the seal.

Mr. Altson is drafting group supervisor at Hyatt Bearings. Employed by GM in December 1946 as a designer at this Division, he was promoted to design engineer in December 1950 and to his present position in April 1952. Mr. Altson received the teacher's diploma from Regent Technical Institute, London, England, in 1930. This is the first patent resulting from Mr. Altson's work in the field of journal box design. He is a member of the American Society of Tool Engineers.

- **Harry P. Henderson**, *New Departure Division, Bristol, Connecticut, for an Electroprocessing Apparatus, No. 2,646,398, issued July 21.* This patent relates to an improved method and apparatus for cleaning and/or electroprocessing work pieces. The work pieces are fed horizontally into and out of closely spaced treatment baths through solutions flowing out of weirs at each end of the baths, thus eliminating complicated apparatus for lifting the work pieces.

Mr. Henderson serves as general superintendent of forging, annealing, and machining at New Departure. He received the B.S. degree in chemistry in 1924 from Tufts College and was employed by General Motors in November 1925 as a chemist at this Division. He is a member of the American Society for Metals.

- **Robert R. Candor**, *Frigidaire Division, Dayton, Ohio, for a Domestic Appliance, No. 2,647,385, issued August 4.* This patent deals with a clothes washing machine of the flexible bag type, provided with an agitator within the flexible bag. The bag is not only contracted by vacuum, but also is expanded by vacuum during the washing and clothes removing operations.

Mr. Candor is assistant patent counsel in the Patent Section at Frigidaire. Employed in August 1925 as a patent searcher in the GM Patent Section in Washington, D. C., he became patent attorney at Frigidaire in November 1928 and was promoted to supervisor of the Frigidaire Patent Section in 1952. Mr. Candor received the B.S. degree in 1912 from Wooster University. He is a member of the bar in Washington, D. C. and Ohio and belongs to the Dayton Patent Bar Association. Mr. Candor's work has resulted in a total of 44 patents in the field of refrigerator and domestic appliances.

- **Albert L. Macan**, *Electro-Motive Division, LaGrange, Illinois, for a Bell Ringing Apparatus, No. 2,647,487, issued August 4.* This patent relates to a locomotive-type bell having a pneumatically actuated clapper and represents improvements over prior designs in respect to the resilient mounting of the bell and to the separating out of water and dust from the live air supplied to the clapper motor.

Mr. Macan is air brake engineer at Electro-Motive in which capacity he is responsible for air brakes and automatic train control development. In 1934 he was employed in the Engineering Department of the Electro-Motive Company, Cleveland, Ohio, predecessor of the Electro-Motive Division of GM. He was promoted through the positions of leading draftsman, designer of air brake layout, assistant section engineer, and section engineer to his present position in November 1948. Mr. Macan is an engineering graduate of the International School of Correspondence. He is a member of the Air Brake Association.

- **Adolph F. Braun**, *Buick Motor Division, Flint, Michigan, for a Compound Carburetion System, No. 2,647,502, issued August 4.* This patent relates to compound carburetors having primary and secondary passages which successively supply the fuel charge. Mechanical movement of the primary and secondary throttles in these passages is correlated to appropriately vary the relative amount of charge supplied by these passages.

Mr. Braun is a section engineer in the Engine Division at Buick Motor. He received the B.S.M.E. degree from University of South Dakota in 1928 and in July of the same year was employed by Buick Motor as a student engineer. He advanced later to the positions of engineer and senior project engineer. Mr. Braun's current work is on power development and carburetion and this is the second patent resulting from his research on carburetion systems. He is a member of Pi Sigma Pi and the Society of Automotive Engineers.

• **John E. Storer, Jr.** and **William G. Livezey,** *Allison Division, Indianapolis, Indiana, for an Overrunning Clutch, No. 2,647,599, issued August 4.* This patent is directed to an overrunning clutch in which power is transmitted through jaw clutch teeth, together with means responsive to relative rotation of the driving and driven shafts for automatically moving the teeth into and out of engagement.

Mr. Storer has been chief engineer in the Transmission Engineering Department at Allison since February 1951. He was originally employed by Buick Motor Division in July 1929 as a General Motors Institute student, graduating from the Institute in 1932. He transferred to Allison Division in July 1940 and was promoted to chief ordnance engineer in October 1946. This is the fifth patent resulting from his work in the fields of carburetion and transmissions. He has authored several papers on military torque converter transmissions.

Mr. Livezey is chief designer in the Transmission Engineering Department at Allison. He joined Allison in January 1936 as an experimental assembler. He was promoted through test engineer, senior test engineer, and senior project engineer. He was appointed to his present position in August 1952. Mr. Livezey is a 1937 mechanical engineering graduate of the International School of Correspondence. This is the first patent that has resulted from his present project on transmission design studies.

• **Jack M. Leet,** *AC Spark Plug Division, Flint, Michigan, for a Filter, No. 2,647,637, issued August 4.* This patent is directed to a new type of spiral filter wherein a double strip of filter material is wrapped about a central support in order to provide separate spiral passages for the filtered and unfiltered fluids, a single external layer of paper being used as an outer protective cover. This filter construction makes it possible to form a spiral filter and the protective cover is one simple wrapping or winding operation.

Mr. Leet is a designer at AC Spark Plug. Originally employed by AC Spark Plug in September 1943 as a senior detailer, he was promoted to layout man in April 1950 and to designer in May 1953. This is the first patent resulting from Mr. Leet's work in oil filter design.

• **Sylvester M. Schweller,** *Frigidaire Division, Dayton, Ohio, for a Compressor, No. 2,647,683, issued August 4.* This patent deals with a reciprocating compressor of a refrigerating system. The capacity of the compressor can be varied by adjusting a plug which is threaded within the head of the piston to vary the effective clearance between the piston and the cylinder head.

At the time of his death in August 1953, **Mr. Scheweller** had been director of engineering at Frigidaire for three years. He joined the Dayton Engineering Laboratories Company in 1916 as a draftsman. In 1925 he became general foreman in charge of all Frigidaire assembly operations. Two years later he was appointed superintendent of Frigidaire's Taylor Street Plant and in 1937 was named chief engineer.

• **Charles A. Chayne,** *Central Office Engineering Staff, Detroit, Michigan, for a Vehicle Door Locking Means, No. 2,647,789, issued August 4.* This invention relates to an auxiliary locking means for a vehicle door in which the door is locked at its hinge side and at its free side to the adjacent body pillar by means of a hydraulically operated lock. In addition, the door is provided with a reinforcing beam so that strains on the door are distributed between the front and rear door pillars, and the door, when locked, is effectively an integral part of the body.

Mr. Chayne's biography was published previously on page 63 of the June-July 1953 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

• **Orson V. Saunders,** *Frigidaire Division, Dayton, Ohio, for a Refrigerator Shelf, No. 2,647,812, issued August 4.* This patent deals with a domestic refrigerator wherein the dishes can be more easily placed and removed. This is accomplished by providing, within the food compartment, a rectangular shelf which can be rotated notwithstanding its occupying substantially the entire cross-sectional area of the food compartment.

Mr. Saunders is supervisor of the major product line in the Household Engineering Department at Frigidaire. Employed as a senior detailer in May 1936, he was promoted through the positions of layout draftsman, designer, senior layout man, experimental engineer, project engineer, senior project engineer, and section engineer to his present position.

• **William D. Chilton,** *Fisher Body Division, Detroit, Michigan, for a Clip Clinching Tool, No. 2,647,814, issued August 4.* This patent covers a pneumatic tool for clinching U-shaped clips, such as are used in securing springs in place during assembly of automobile seats. A pair of jaws pivotably mounted on the tool head cooperate with each other to secure the work pieces in position and form an anvil and guide for the clip which is advanced to effect its clinching by a percussively actuated ram.

Mr. Chilton is engineer-in-charge of the Design and Shop Group of the Process Development Plant, Fisher Body. He was originally employed by the St. Louis Plant of Fisher Body as a maintenance electrician in May 1926. He was transferred to the Central Development and Experimental Department as an experimental engineer in 1938, later transferred to the Memphis Plant as engineer-in-charge of the Tool Engineering Section, and made assistant engineer-in-charge of the Mechanical Section, Detroit, in 1945. His work in the development of nut sorters for aircraft rivets and cloth laying machines has resulted in seven patents.

• **Robert N. Falge,** *Guide Lamp Division, Anderson, Indiana, for a Headlight Bezel Ring Mounting, No. 2,647,984, issued August 4.* This patent covers an improvement in headlamp structure wherein the headlamp bezel is secured to the lamp casing by means of a spring wire clip. The clip has leg portions which snap into the bezel and a lug portion which fits into a slot in the casing.

Mr. Falge's biography was published previously on page 54 of the September-October 1953 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

• **Clarence H. Jorgensen, Willard T. Nickel, Howard T. Dietrich,** *and* **Donald P. Worden,** *Rochester Products Division, Rochester, New York, for Jet Engine Fuel Controller, No. 2,648,194, issued August 11.* This patent relates to a device for positioning the valve controlling fuel flow to jet engine burners. A fuel valve is manually controlled through a reversible motor under automatic modification responsive to change in speed and temperature which prevents too fast a manual change.

The biographies of **Messrs. Jorgensen, Nickel, Dietrich,** and **Worden** were published previously on page 35 of the June-July 1953 issue of the GENERAL MOTORS ENGINEERING JOURNAL.

• **Rea I. Hahn and B. E. Frank,** *Rochester Products Division, Rochester, New York, for an Apparatus for Cutting Tubing, No. 2,648,384, issued August 11.* This patent relates to a device for cutting steel tubing into selected lengths as it leaves the tube mill without stopping the tubing or moving the cutter. A solenoid, responsive to tube movement, operates a shear blade at sufficient speed to accomplish this.

Mr. Hahn is works manager at Rochester Products. He started with the Corporation in February 1934 as a gear cutter at Delco-Remy Division. He was promoted through the positions of foreman, process engineer, supervisor of tubing production, metallurgist, and technical director—all at Delco-Remy. In July 1950 he was transferred to Rochester Products as works manager. Mr. Hahn received the B.S. degree in chemical engineering from Purdue University in 1932. He is a past local chairman of the American Society of Metals and a member of the American Welding Society and the Management Clinic at University of Rochester.

Mr. Frank is senior engineer in the Tubing Engineering Department of Rochester Products. He received the civil engineering degree from Ecole Speciale D'Inginieur Technicien, Charleroi, Belgium, in 1939. Originally employed by General Motors as a senior designer at Rochester Products in February 1945, Mr. Frank was promoted to senior engineer in November 1949 and to senior engineer in charge of tubing fabrication engineering in October 1951. His work in the field of fabrication of tubing has resulted in 10 patents. He is a member of the American Society of Mechanical Engineers.

• **Jean A. Lignian,** *Moraine Products Division, Dayton, Ohio, for an Aluminum Base Bearing, No. 2,648,580, issued August 11.* This patent pertains to a bearing having an aluminum base with or without a steel backing. The base is grooved transversely to the direction of rotation and overlaid with babbitt, thus providing superior run-in characteristics.

Mr. Lignian is chief engineer at Moraine Products. Originally employed by Chevrolet Motor Division in July 1927 as a dynamometer operator, he completed his studies at University of Michigan to receive the B.S. degree in electrical engineering in 1928. He was transferred to Moraine Products in October 1936 as experimental engineer. He is the author of a paper on the material characteristics and design data of Durex-100 engine bearings. He is a registered professional engineer, and a member of the Engineers Club of Dayton and the S.A.E. where he serves on the Engine Bearings Subcommittee.

• **Taine G. McDougal,** *AC Spark Plug Division, Flint, Michigan, for a Combuster Igniter Cup which becomes Incandescent from Combustion Therein, No. 2,648,951, issued August 18.* The invention disclosed in this patent relates to a compact, low voltage incandescent glow plug for igniting fuel flowing at high velocity, such as is present in jet engines.

Mr. McDougal is director of research and spark plug engineering at AC Spark Plug. He received the ceramic engineering degree from Ohio State in 1911. In October 1914 he was employed by AC Spark Plug as a ceramic engineer. Mr. McDougal's work with spark plugs, spark plug insulator compositions, drying and firing apparatus, and synthetic jewel bearings have resulted in 41 patents and a published paper on the casting of clay wares. He is a Fellow of the American Ceramic Society and is a member of Sigma Xi, Sigma Delta Chi, and the Society of Automotive Engineers.

• **Elbridge F. Bacon** *AC Spark Plug Division, Flint, Michigan, for a Signal Reflector for Automotive Vehicles and the Like, No. 2,649,029, issued August 18.* This patent involves a novel street signal reflector for automobiles and forms an instrument cluster part which is rotatable into positions wherein the reflector can be seen by the vehicle operator or in which the surface of the part merges with the trim rail.

Before his death in December 1949, **Mr. Bacon** was assistant chief engineer at AC Spark Plug. He was with this Division as an engineer for 23 years and became one of the foremost authorities on automotive instruments and related devices. During World War II he contributed to the production of bombsights and gunsights produced by AC Spark Plug for the United States Air Forces and the Royal Air Force of Great Britain.

• **Glen A. Smith,** *General Motors Overseas Operations Division, Detroit, Michigan, for a Vehicle Door Lock, No. 2,649,321, issued August 18.* This patent involves a door lock of the push and pull outside door handle type. It includes a safety lock mechanism which can be used to prevent a door from being unlocked from inside or outside the vehicle.

Mr. Smith handles styling liaison in GM Overseas Operations. Employed in September 1934 as a draftsman in GM Export, he has since done work for GM India in 1937-38, the Styling Section in 1943-45, and GM do Brasil in 1940-43 and 1945-48. He received the aeronautical engineering degree from University of Detroit in 1931. This is the third patent resulting from Mr. Smith's work on door locks and body construction. He is a member of the S.A.E. and the Engineering Society of Detroit.

• **Roland V. Hutchison and Maurice A. Thorne,** *General Motors Engineering Staff, GM Technical Center, for a Driven Steering Wheel, No. 2,649,922, issued August 25.* This patent is directed to a new sealed bearing arrangement employed in connection with the sealed front wheel brake assemblies on military vehicles. A sealed ball bearing is employed in combination with a roller bearing and two other seals.

Mr. Hutchison serves as assistant head of the Vehicle Development Group of the Engineering Staff. He began his GM employment in February 1919 as assistant to the chief mechanical engineer at Dayton Metal Products, forerunner of Research Laboratories Division. Most of his career, however, was spent on various engineering assignments with the Oldsmobile Division. He was appointed to his present position in 1941. He is a member of the S.A.E., the A.S.M., and serves as an alternate to the vice president-in-charge of Engineering on the Research and Development Board of the Engine-Fuel Committee of the Army.

Mr. Thorne has been engineer in charge of the Vehicle Development Group of the Engineering Staff since July 1952. He joined the Engineering Staff in August 1941 following seven years with the Oldsmobile Division Engineering Department. During World War II, Mr. Thorne was chief engineer on the heavy tank M-26 and related pilot models at Fisher Tank Division. He received the B.A. degree from George Washington University in 1922. This is the third patent resulting from Mr. Thorne's work on passenger car development. He is a member of the Society of Automotive Engineers.

Recent Speaking Engagements Filled by GM Engineers

Appearances by GM engineers before technical societies, classrooms, and civic and fraternal groups are one medium through which news about General Motors engineering progress and projects reach outside the Corporation. These appearances are encouraged by the Divisions as part of their program of sharing engineering information with the public. The period covered in this report is from August 16 through October 16.

Walter Eitel, general supervisor of tool engineering and methods at AC Spark Plug Division, completed two speaking engagements during September. On September 23 in Chicago, he was part of a panel before the Society for the Advancement of Management discussing "Our Experience with Student Engineers." His next engagement was on September 24 before the National Association of Foremen at Milwaukee where he discussed "Work Simplification and the Foreman."

G. S. Cole, manufacturing manager of Brown-Lipe-Chapin Division, Syracuse, was on the panel, "Management's Stake in the Safety Program" at the fall meeting of the Central New York Chapter of the American Society of Safety Engineers.

James H. Smith, general manager of the Central Foundry Division, addressed the Saginaw Valley Chapter of the American Foundrymen's Society on October 1 at Frankenmuth, Michigan.

Mauri Rose, senior experimental engineer, and **Z. Arkus-Duntov**, assistant staff engineer, both of the Research and Development Department of Chevrolet Motor Division, spoke on "Some Technical Aspects of Racing Here and Abroad" before the Detroit Section of the Society of Automotive Engineers at White Sulphur Springs, West Virginia, on September 12. On September 28, Mr. Rose and Mr. Arkus-Duntov spoke to the Mid-Michigan Chapter of the S.A.E. at Lansing on "Sports Cars."

C. W. Frederick, assistant chief engineer in the Production Engineering Department of Chevrolet Motor Division, spoke to the Kansas City Section of the S.A.E., September 29, on "What Engineering Management Requires of the Engineer."

On October 1 at Baltimore, **Mauri Rose** was part of the S.A.E. Symposium on Sports Cars. At the Detroit Section of the S.A.E., **Z. Arkus-Duntov**, on October 5, described the "Le Mans Race."

Four Chevrolet Motor Division personnel spoke on the new Corvette. The principal speaker at the Kansas City Chapter S.A.E. meeting on September 28 was **C. W. Frederick**, assistant chief engineer at Chevrolet Motor Division. His topic was "Manufacturing Problems—Corvette." **Maurice Olley**, director of the Research and Development Department, discussed "The Evolution of a Sports Car—The Chevrolet Corvette" at the October 5 meeting of the Detroit Section of the S.A.E. Mr. Olley discussed this same subject on October 13 before the Chicago Section of the S.A.E. At the October 15 meeting of the American Society of Mechanical Engineers in Schenectady, **Mauri Rose** and **W. S. Wolfram**, assistant staff engineer in Chevrolet's Research and Development Department, presented "A Discussion of the Corvette Car."

Bernard A. Schwarz, chief engineer at Delco Radio Division, took part in the School Teachers Business-Industry-Education Day on September 3 at Kokomo, Indiana. He discussed "Engineering Organization Requirements and Product Responsibility."

A Delco-Remy quality engineer, **Arthur Bender**, spoke before the Eighth Forum of the Michigan Section of the American Society for Quality Control. His talk, given on September 12 at the University of Michigan, was entitled "A Quick Method for Determining Characteristics of the Frequency Distribution."

On September 19, during the same meeting, Mr. Bender delivered a talk on "Quality Control."

On October 1, at the Pittsburgh Regional Management Controls Conference of the American Society for Quality Control, Mr. Bender discussed "What Are Your Chances." During the Mid-West Quality Control Conference, American Society for Quality Control, held on October 8, at Davenport, Iowa, Mr. Bender described "Probability Paper."

Three Electro-Motive Division engineers spoke at the Diesel Engine Manufacturers' Association Educational Meeting on October 6. **E. W. Kettering**, chief engineer of the Engineering Department, presented a "Discussion of the Locomotive Development Center" and "Prime Mover Characteristics." **J. R. Ware**, chief mechanical engineer in the Mechanical Section, spoke on the "Development of the 567 Engine" and **L. Petersen**, chief structural engineer in the Structural Test Department, discussed "Instrumentation."

The chief metallurgist at Electro-Motive Division, **L. E. Simon,** was one of two speakers in a panel discussion at the Interstate Machinery Company's fourth annual industrial clinic and machinery fair, in Chicago, on October 15. His subject was "Steel Selection for Strength."

William E. Sehn, senior project engineer in the Standard Parts and Glass Department of Fisher Body Division, explained the "Engineering Society of Detroit Company Representative Plan" to the E.S.D. on September 16.

Henry A. Weil, project engineer in the Textile Laboratory of Fisher Body Division, outlined "The Textile Engineer and the Automotive Industry" to the American Society of Body Engineers at their October 29 meeting in Detroit.

Floyd A. Franklin, coach engineer at GMC Truck and Coach Division, described "Air Suspension for Vehicles" to the Great Lakes Greyhound and Suburban Community Officials on September 11 at Farmington, Michigan.

"Application of Carbide Tools" was the talk given by **Clyde L. Fanning,** assistant chairman of the Machine and Wood Shop, General Motors Institute, during the Machinability Conference held at the University of Michigan on August 26.

The assistant director of the General Motors Proving Ground, Milford, **Louis C. Lundstrom,** described "Automotive and Military Testing at GM Proving Ground" to the U. S. Naval Reserve Supply Corps Officers on September 28 in Washington, D. C. On October 15, Mr. Lundstrom spoke to the Dayton Section of the S.A.E. on "Automotive Testing at General Motors Proving Ground."

David Apps, head of the Noise and Vibration Laboratory at the Proving Ground, described the "Operations of the General Motors Proving Ground" to the Kalamazoo Engineers Club on October 8.

Edward Williamson, of the Patent Section and patent attorney in charge of the London office, delivered a talk on the outstanding broad technical and industrial problems confronting England. Entitled "Trans-Atlantic Commentary," the talk was given to the Michigan Patent Law Association at the Meadowbrook Country Club, Northville, Michigan, on September 22.

Hyatt Bearings Division sales engineer, **Louis C. Fisk,** spoke to the Newark Chapter of the American Society of Tool Engineers on September 8. The title of his talk was "A Discussion of Fundamentals of Anti-Friction Bearings Including Application and Maintenance."

Donald C. Burnham, assistant chief engineer of the Product Engineering Department at Oldsmobile Division, discussed "Industrial Engineering—the Key to Effective Management" at the Industrial Engineering Conference in East Lansing, Michigan, on September 14. On September 30, Mr. Burnham spoke before the Lansing Chapter of the American Society of Tool Engineers on "Relation of the Product Engineer to the Tool Engineer."

At the Industrial Engineering Conference held in Lansing, **R. H. Whiters,** plant layout engineer, and **J. R. Seip,** foreman in the Inspection Department, gave talks. Mr. Whiters, on September 15, described "Plant Layout at Oldsmobile." On September 17, Mr. Seip discussed "Quality Control at Oldsmobile."

Mr. Whiters, on September 22, appeared at Grand Rapids before the Western Michigan Chapter of the American Materials Handling Society and discussed "Plant Layout and Materials Handling."

R. J. Cook, chief inspector of the Inspection Department at Oldsmobile, explained how "Oldsmobile Obtains More Results with Fewer Charts" to the Michigan Society for Quality Control, on September 19, at the University of Michigan, Ann Arbor, Michigan.

"Oldsmobile's Dual-Purpose Operations" were outlined to the Junior Industrial Club in Lansing, Michigan, on October 1, by **Marshall D. McCuen,** foreman of the Jet Engine Plant.

Edward J. Martin, head of the Physics and Instrumentation Department of the Research Laboratories Division, and **Gilford G. Scott,** special technician to C. F. Kettering, described "An Advanced Project on Magnetism" to the Fisher Body Craftsman Guild at the Research Laboratories, Detroit, on August 18.

"The Vagaries of Paint Testing" was the title of the talk given by **Ralph J. Wirshing,** head of the Chemistry Department, Research Laboratories, to the New Hampton School, New Hampton, New Hampshire, on August 20.

Charles L. McCuen, general manager of the Research Laboratories, described "Research in GM" to the Sloan Executive Development Group on September 17 at the GM Technical Center. On October 1, Mr. McCuen spoke on "Relations with Engineering Personnel"* at the 1953 GM Personnel Conference held in the General Motors Building, Detroit.

Before the September 24 meeting of the National Council of Teachers of Mathematics held at Western Michigan College, **Arvid E. Roach,** supervisor of bearing development in the Mechanical Department, discussed the "Mathematical Methods in Engineering Research."

During the National Physical Laboratory's Symposium on Engineering Dimensional Metrology meeting in London, England, from October 21 to 24, **Arthur F. Underwood,** head of the Mechanical Development Department, Research Laboratories Division, described "Two Recent Developments for Accurate Measurement of Surface Roughness."

Thomas A. Boyd, consultant to the Research Laboratories Division, related research to technical societies in his talk "Better Many Heads" given to the Northern Michigan Technical Society at Traverse City, Michigan, on September 28. Mr. Boyd described the organizing of a research laboratory to the Midland Engineering Society, Midland, Michigan, on October 13 in his talk "Solomon's House."

"Saginaw Power Steering" was described by **Clovis W. Lincoln,** chief engineer of Saginaw Steering Gear Division, on August 17 to the Rotary Club of Breckenridge, Michigan; on September 9 to the Shrine Caravan Club at Saginaw, and on October 9 to the Michigan Education Association at Saginaw.

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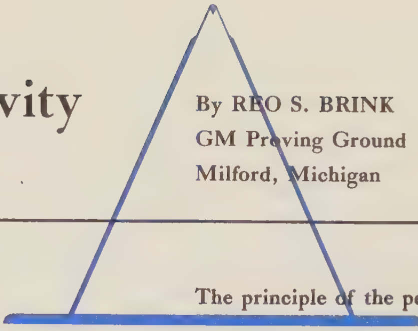
*The paper beginning on page 32 is Mr. McCuen's adaptation of his talk for the GENERAL MOTORS ENGINEERING JOURNAL.

The Solution of the Center of Gravity and Moment of Inertia Problem



By REO S. BRINK
GM Proving Ground
Milford, Michigan

The principle of the pendulum aids automotive testing

Using data compiled from two specially constructed automobile swings and applying general physics equations, engineers can determine accurately the height of the center of gravity and the moment of inertia of an automobile—two factors which affect safe and comfortable driving. This is the solution to the problem presented in the September-October GENERAL MOTORS ENGINEERING JOURNAL. It follows the steps the engineer used in solving the actual problem.

THE moment of inertia of a compound pendulum about its axis of oscillation I' is given by equation (1) in Table I,

where

g = acceleration due to gravity

T = period of oscillation in seconds

W = weight of the pendulum

L = distance from the center of gravity of the pendulum to its axis of oscillation.

Equation (2) gives the moment of inertia of a pendulum about its center of gravity I.

These general equations apply to an undamped compound pendulum oscillating with a small amplitude in a vacuum. The next step in the solution is to apply these equations to the automobile on the swings.

Let

I = moment of inertia of car about its center of gravity

I_s = moment of inertia of swing about knife edge (axis of oscillation)

I_c = moment of inertia of car about knife edge of swing

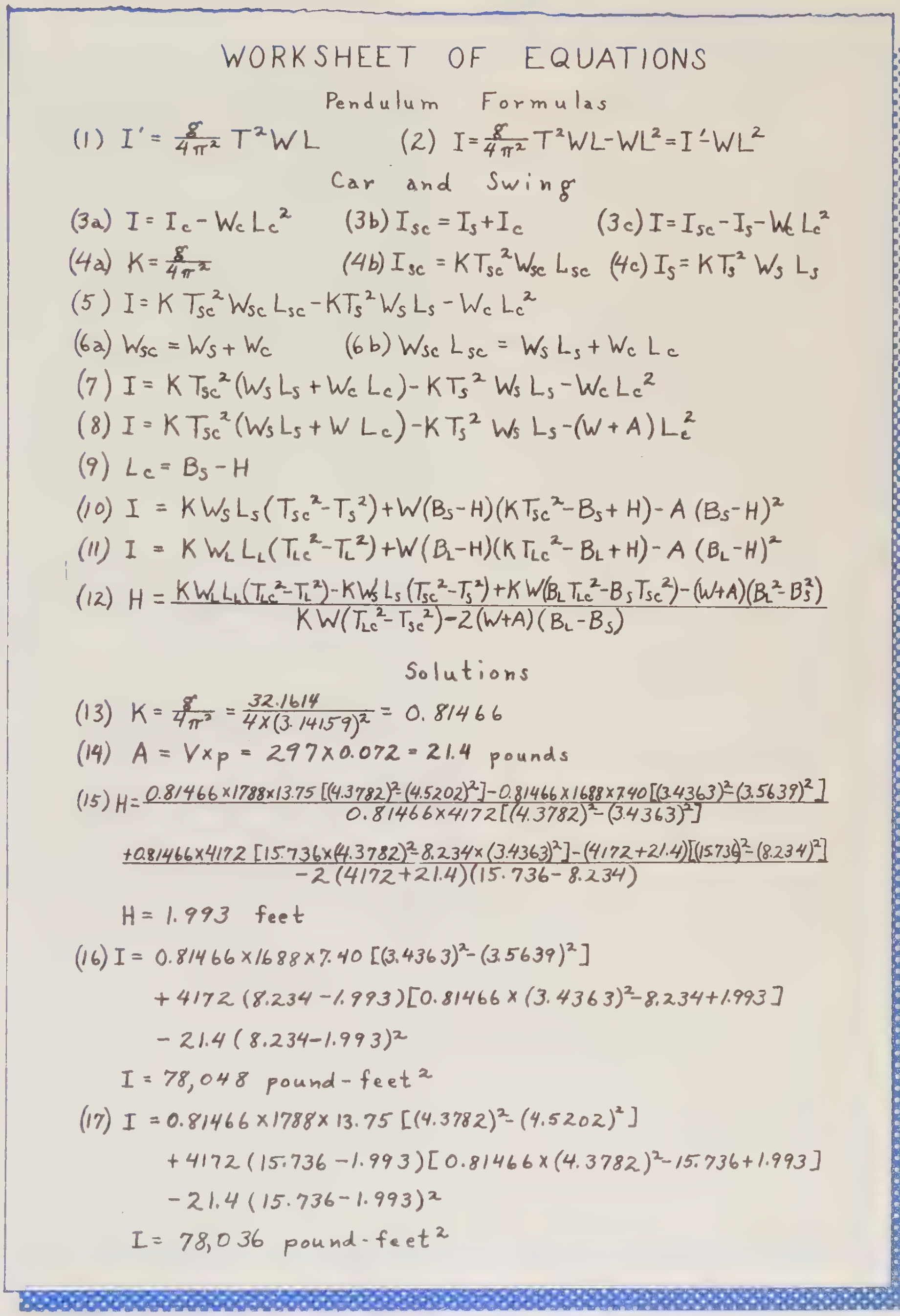
I_{sc} = moment of inertia of swing with car in place about knife edge

W_c = weight of car

W_s = weight of swing

W_{sc} = weight of car plus weight of swing

L_c = distance from axis of oscillation to center of gravity of car.



WORKSHEET OF EQUATIONS

Pendulum Formulas

(1) $I' = \frac{g}{4\pi^2} T^2 W L$ (2) $I = \frac{g}{4\pi^2} T^2 W L - W L^2 = I' - W L^2$

Car and Swing

(3a) $I = I_c - W_c L_c^2$ (3b) $I_{sc} = I_s + I_c$ (3c) $I = I_{sc} - I_s - W_c L_c^2$

(4a) $K = \frac{g}{4\pi^2}$ (4b) $I_{sc} = K T_{sc}^2 W_{sc} L_{sc}$ (4c) $I_s = K T_s^2 W_s L_s$

(5) $I = K T_{sc}^2 W_{sc} L_{sc} - K T_s^2 W_s L_s - W_c L_c^2$

(6a) $W_{sc} = W_s + W_c$ (6b) $W_{sc} L_{sc} = W_s L_s + W_c L_c$

(7) $I = K T_{sc}^2 (W_s L_s + W_c L_c) - K T_s^2 W_s L_s - W_c L_c^2$

(8) $I = K T_{sc}^2 (W_s L_s + W L_c) - K T_s^2 W_s L_s - (W + A) L_c^2$

(9) $L_c = B_s - H$

(10) $I = K W_s L_s (T_{sc}^2 - T_s^2) + W (B_s - H)(K T_{sc}^2 - B_s + H) - A (B_s - H)^2$

(11) $I = K W_L L_L (T_{Lc}^2 - T_L^2) + W (B_L - H)(K T_{Lc}^2 - B_L + H) - A (B_L - H)^2$

(12) $$H = \frac{K W_L L_L (T_{Lc}^2 - T_L^2) - K W_s L_s (T_{sc}^2 - T_s^2) + K W (B_L T_{Lc}^2 - B_s T_{sc}^2) - (W+A)(B_L^2 - B_s^2)}{K W (T_{Lc}^2 - T_{sc}^2) - 2 (W+A)(B_L - B_s)}$$

Solutions

(13) $K = \frac{g}{4\pi^2} = \frac{32.1614}{4 \times (3.14159)^2} = 0.81466$

(14) $A = V \times p = 297 \times 0.072 = 21.4$ pounds

(15) $$H = \frac{0.81466 \times 1788 \times 13.75 [(4.3782)^2 - (4.5202)^2] - 0.81466 \times 1688 \times 7.40 [(3.4363)^2 - (3.5639)^2] + 0.81466 \times 4172 [15.736 \times (4.3782)^2 - 8.234 \times (3.4363)^2] - (4172 + 21.4)[(15.736)^2 - (8.234)^2]}{0.81466 \times 4172 [(4.3782)^2 - (3.4363)^2] - 2 (4172 + 21.4)(15.736 - 8.234)}$$

$H = 1.993$ feet

(16) $I = 0.81466 \times 1688 \times 7.40 [(3.4363)^2 - (3.5639)^2]$
$+ 4172 (8.234 - 1.993)[0.81466 \times (3.4363)^2 - 8.234 + 1.993]$
$- 21.4 (8.234 - 1.993)^2$

$I = 78{,}048$ pound-feet^2

(17) $I = 0.81466 \times 1788 \times 13.75 [(4.3782)^2 - (4.5202)^2]$
$+ 4172 (15.736 - 1.993)[0.81466 \times (4.3782)^2 - 15.736 + 1.993]$
$- 21.4 (15.736 - 1.993)^2$

$I = 78{,}036$ pound-feet^2

Table I—Engineer's worksheet showing the order of equations used to determine the height of the center of gravity and the moment of inertia of the automobile being tested on the swings. The height of the center of gravity of this particular car H is *1.993 ft* or *23.9 in.* The moment of inertia I is *78,050 lb-ft²*.

Making these substitutions into equation (2) gives (3a). Replacing I_c in the latter equation with its equivalent value obtained from (3b) gives (3c).

Letting K equal the assigned value given in (4a), and substituting this into (1) results in (4b) in which L_{sc} is the distance from the axis of oscillation to the center of gravity of both the car and the swing together. This value falls somewhere between the center of gravity of the swing and that of the car. Equation (4c) applies to the swing alone.

Next, substitute (4b) and (4c) into (3c) to get equation (5).

The weight of the car plus the weight of the swing equals the weight of the two combined W_{sc}. Equation (6b) follows from the fact that the total moment of a system is equal to the sum of the individual moments. To get equation (7) substitute (6a) and (6b) into (5).

Up to this point, it has been assumed that the pendulum was undamped and in a vacuum. While the problem states that the damping on the pendulum in the photo-cell was less than 0.002 per cent and could be ignored, the weight of the air contained in and displaced by the car causes an error of from ¾ to 1 in. in the height of the center of gravity of the car and, consequently, cannot be neglected.

The *mass* of the car is equal to its weight in air plus the weight of the air displaced by the material in the car. The *over-all volume* of the car is the sum of the volume of the displaced air plus the volume of the entrapped air. If V equals the volume of the car; p equals the density of air; A equals the weight of the air displaced and entrapped; and W equals the weight of the car in air—then, A equals V times p; W plus A equals the total mass of the car and entrapped air. The inertia of the car is dependent upon this total mass of the car and the entrapped air (W plus A). The force exerted upon the car by gravity depends upon W.

In (7) replace W_c in the first term by W because this is an expression of force exerted upon the system by gravity and is dependent upon the observed weight. Replace W_c in the last term of (7) by $W + A$ because this is an expression which refers the moment of inertia to a parallel axis, and is dependent upon the mass. The swing itself displaces and entraps such a small mass of air that it can be considered negligible.

Replacing these two terms results in (8). Equation (9) is apparent from the diagram (Fig. 1). Equation (10) is the result of substituting (9) into (8).

If subscript s denotes the short swing and subscript l denotes the long swing, then (10) and (11) give I the moment of inertia of the car about its center of gravity for each respective swing. The values of I and H remain the same for the car being tested on both the long swing and the short swing. All of the values in (10) and (11) are constants and, with the exceptions of I and H, may be measured. Solving the two equations simultaneously for H gives the height of the center of gravity of the car (12).

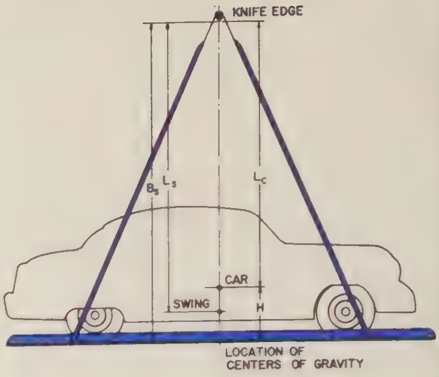


Fig. 1—Diagram of the short automobile swing. The subscript s denotes the short swing, H represents the height of the car's center of gravity, L_c represents the length from the knife edge to the automobile's center of gravity, B_s represents the distance from the knife edge to the floor of the swing, L_s represents the distance from the knife edge to the center of gravity of the swing.

Car Data		
Test Weight of Car—lb	$= W = 4172$	
Overall Volume of Car—cu ft	$= V = 297$	
Periods of Oscillation—Seconds	*Short Swing*	*Long Swing*
Swing Alone	$T_s = 3.5639$	$T_l = 4.5202$
With Car in Place	$T_{sc} = 3.4363$	$T_{lc} = 4.3782$
Swing Constants	*Short Swing*	*Long Swing*
Weight—lb	$W_s = 1688$	$W_l = 1788$
Knife Edge to Floor of Swing—ft	$B_s = 8.234$	$B_l = 15.736$
Knife Edge to Center of Gravity—ft	$L_s = 7.40$	$L_l = 13.75$
Conditions at Test Site		
Acceleration due to gravity—ft/sec²	$= g = 32.1614$	
Average density of air—lb/ft³	$= p = 0.072$	

Table II—Observed and calculated values for the test car on the swings.

Substituting the values in Table II into the formula for K gives the equation (13). Inserting the given values into the formula for A results in (14). Then substituting all the known and calculated values into equation (12) to find the height of the center of gravity of the car gives (15) with the calculated value of H equal to *1.993 ft* or *23.9 in. above the ground.* Using the values given, H should not vary by more than ±0.001 ft from this value. The accuracy of the test is probably within =0.25 in. Substituting this value of H and other known values into the formula for the moment of inertia of the car on the *short* swing (10) gives (16) in which I is equal to *78,048 lb-ft²*. Substituting known values into (11), the formula for the *long* swing, gives equation (17). According to (17), I is equal to *78,036 lb-ft²*. This is within 30 lb-ft² of the value from the short swing as stated in the problem. Each of these last two values may vary by ±50, depending upon the number of places past the decimal carried through the calculations. Averaged and rounded off to the nearest 50, the moment of inertia would be expressed as being *78,050 lb-ft²*.

A Typical Problem in Automotive Design: Determine the Most Economical Strip Length for a Bracket

A simple bracket connecting two points in an automotive application is stamped from a metal blank. In the manufacture of this relatively minor part, tremendous savings in material result from the careful calculation of the blank length.

By CHARLES M. RUBLY
Chevrolet Motor Division

Where one inch
saved means
35 tons of steel

ONE of the major responsibilities of the engineer is to use material in the most efficient manner possible. This is especially true in the automotive industry where any squandering of material can have serious economic consequences.

A scrap of superfluous metal is multiplied by the hundreds of thousands of times it will be reproduced in just one year and usually by millions before it is replaced, some years later, by a new design. Through the years, fractions of ounces of superflous metal snowball into tons of metal wasted.

Chevrolet, being the largest producer in the automotive industry, has the most to gain from efficient design. For example, one in. of material saved on the length of a strip bracket (based on an estimate of 2,000,000 unit production) equals approximately 167,000 ft or over 31.5 miles of material saved. If the material is one in. wide and 0.120 in. thick, the strip stock saved would equal 70,500 lb or over 35 tons of steel.

Problem

The problem is to connect point *A* and point *B*, shown in Fig. 1, by a simple bracket and to do it quickly and efficiently.

The material to be used is 0.120 by 1.00 in. steel strip. Holes for fasteners shall be $\frac{3}{8}$ in. diameter and there shall be a minimum of $\frac{5}{16}$ in. of metal between the edge of the hole and the edge of the part. All radii shall be $\frac{1}{8}$ in. to the inside of the metal. The length of the material used for the bends may be estimated by allowing 0.0288 in. per every 10° of the bend.

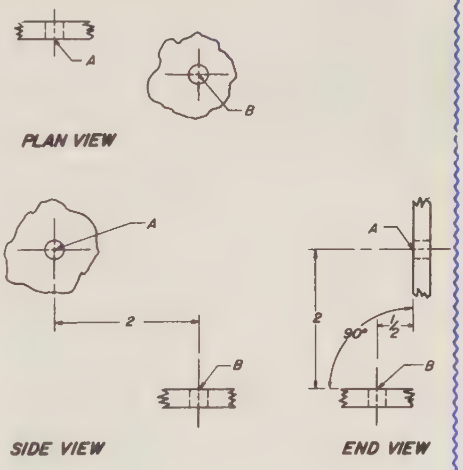


Fig. 1—Principal dimensions between points A and B, which are to be connected by a metal bracket.

Make a layout drawing of the simplest bracket to attach these points and specify the length of strip steel needed for the blank.

The solution of the problem will be presented in the next issue of the JOURNAL.

ENGINEERING EDUCATORS
For a message about the GENERAL MOTORS ENGINEERING JOURNAL, kindly see page 43.

GENERAL MOTORS
Engineering
JOURNAL

Contributors

REO S. BRINK, who solves a typical problem in automotive design in the current issue, serves as supervisor of the engineering test data activity of the Engineering Test Department at GM Proving Ground, Milford, Michigan. The solution applies to his problem on "A Method for Determining the Center of Gravity and Moment of Inertia of an Automobile," as presented in the September-October 1953 issue.

The test data activity consolidates results of routine and special tests at the Proving Ground and renders them into publishable form. Mr. Brink has served in technical data capacities almost all of his GM career, which began at Milford in September 1941 as a test engineer. After several months on both laboratory and road tests of automobiles, he was transferred to his present area of service. He became supervisor for the activity in October 1946.

Mr. Brink received the B. S. degree in education in 1939 from Western Michigan College of Education, where he majored in the sciences and mathematics. Just prior to joining General Motors, he taught science and other subjects for two years in a Michigan high school, meanwhile spending his summers as a graduate student in physics at University of Michigan. Earlier he had spent four years as an elementary school teacher.

GILBERT BURRELL,

co-contributor of "A Study in Applied Physics: Locating the Piston Pin to Minimize Piston Slap," serves as motor engineer in the Product Engineering Department at Oldsmobile Division.

In August 1928, after receiving the electrical engineering degree from Michigan State College, Mr. Burrell was employed at Oldsmobile Division as a dynamometer operator. In January 1930, he was transferred to the drafting group on engine design. He was promoted to special project engineer in February 1942, to assistant motor engineer in June 1945, to advanced design engineer in April 1946, and to his present position, motor engineer, in August 1946.

Mr. Burrell's work in engine design and development has resulted in two patents—one on a V-6 engine design, the other for a starter-throttle interconnection. Some of his other projects have included development work on fuel strainers, valve rotating devices, balancing of engines, crankpin arrangements for six-cylinder engines, rocker arm cover, and crankcase ventilating systems.

His technical affiliations include membership in the Society of Automotive Engineers.

F. GIBSON BUTLER,

co-contributor of "A Study in Applied Physics: Locating the Piston Pin to Minimize Piston Slap," serves as a senior designer in the Product Engineering Department at Oldsmobile Division.

Mr. Butler joined Oldsmobile Division in April 1941 as a plant engineer and was engaged in the work of building alterations and installation of equipment for Oldsmobile's 75 mm gun project. Among the devices designed and developed by Mr. Butler in connection with this project were an automatic tire inflating machine and a safety device for an automatic conveyor system. He was made product engineer in August 1944, and he attained his present position in February 1949.

At present, Mr. Butler is principally concerned with analytical design work on crankshaft and valve gear developments. He also is engaged in developing special techniques for testing engines. Previously, he did work on bearing load analysis.

Michigan College of Mining and Technology granted Mr. Butler the B.S. degree in mechanical engineering in 1937. He is a member of the Society of Automotive Engineers. Before joining General Motors, he was engaged in heavy construction work which included such projects as bridges, highways, and railroads.

ROBERT W. ENGLE,

co-contributor of "An Engineering Solution for the Development of a Civilian-Military Factory," is general supervisor of layout and engineering at the Kansas City Plant of the Buick-Oldsmobile-Pontiac Assembly Division. His current major project concerns the rearrangement and augmentation of plant facilities for concurrent assembly of F-84F aircraft and Buicks, Oldsmobiles, and Pontiacs.

Mr. Engle joined GM in 1934 as a student engineer at Fisher Body Division's Tarrytown, New Jersey, plant. After graduating from General Motors Institute in 1936, Mr. Engle had charge of the wood framing line at B.O.P.'s Southgate, California, plant. With the introduction of the all-steel body in 1937, he supervised the body framing or so-called gun line.

Still at the Southgate Plant, Mr. Engle was appointed labor relations representative in the then-new grievance program. After one year he became engineering assistant to the plant engineer. He held this position during a period of major plant rearrangements until March 1943 when he joined the Navy. Mr. Engle was separated in October 1945 with the rank of lieutenant, senior grade. He had served principally as an ordnance specialist.

After World War II Mr. Engle was transferred to the newly opened Kansas City B.O.P. plant as shift superintendent in the body shop. Before assuming his present position he was a senior process engineer responsible for model change planning and production trouble shooting and follow up.

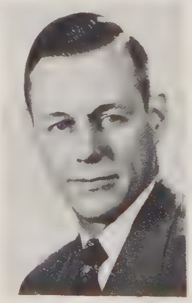
CHRISTIAN G. GOOHS,

contributor of "Torsional Vibrations in Diesel Engines," serves as supervisor of the Vibrations Section of Cleveland Diesel Engine Division's Engineering Department. This section, part of the Technical Department, makes vibration analyses of all new engine designs as well as all marine and generator installations. Engine balance design calculations are also handled by this group.

Mr. Goohs joined Cleveland Diesel Engine Division in September 1939 as a General Motors Institute cooperative student. His work assignments were mainly in production and development engineering and his classroom work in Flint, Michigan, was completed in August 1943. His thesis was in the same area as his current paper and upon its completion he received the B.S.M.E. degree in 1948.

From August 1943 to April 1946, Mr. Goohs served in the Navy, principally as a machinery repair superintendent at the Brooklyn and San Diego Navy Yards. He attained the rank of lieutenant, junior grade.

Upon his return to Cleveland, Mr. Goohs became a junior stress analyst in the Engine Calculation Section. After five months he was transferred to his present section and assumed his present supervisory responsibilities in May 1947. He has prepared vibration reports for use by General Motors engineers, and has been active in the Society of Automotive Engineers and in the Society of Experimental Stress Analysis.



ROBERT L. KESSLER,

contributor of "Technical, Economic, and Human Factors Affecting the Design and Use of Special Machinery," was promoted to manufacturing manager in charge of production in all Anderson, Indiana plants of Delco-Remy Division in October 1953.

Mr. Kessler started with Delco-Remy Division in the Process Department in June 1936 directly after receiving the B. S. degree from Purdue University. In 1941, as foreman, he assisted in the organizing and starting of production in the aluminum foundry of one of the Division's plants. He was promoted, in May 1943, to general foreman of Delco-Remy Plant Eight, which was devoted to wartime production of generators and starting motors for aircraft and heavy duty applications.

One year later he transferred back to the Process Department as chief process engineer. He was named assistant master mechanic in 1950 and was promoted to master mechanic in 1951.

Mr. Kessler's technical affiliations include membership in the Society of Automotive Engineers. His paper appearing in this issue is an adaptation of his talk on this subject presented before the 10th Annual Machine Design Conference of the Cleveland Engineering Society.

CHARLES L. McCUEN,

contributor of "Engineering Personnel Management in a General Motors Division," serves as a vice president of the General Motors Corporation and as general manager of the Research Laboratories Division, Detroit. He obtained his early education in San Francisco and was graduated from the Polytechnic College of Engineering at Oakland, California, in 1911. In 1934 this college conferred an honorary degree on Mr. McCuen.

Mr. McCuen has devoted his entire career to engineering. He began with General Motors in September 1926 on the engineering staff of the Oldsmobile Division. There he designed the F series 6-cylinder and the L series 8-cylinder Oldsmobile engines. He was promoted to chief engineer of Oldsmobile and director of engineering and, in May 1932, he was made technical assistant to the general manager of the Oldsmobile and Buick Motor Divisions of General Motors.

Mr. McCuen was appointed general manager of the Oldsmobile Division in October 1933 and in August 1940 became vice president in charge of the Engineering Staff of General Motors. He assumed his present position in July 1947.

(The nature and scope of work done by the Research Laboratories Division is described in the September-October 1953 GENERAL MOTORS ENGINEERING JOURNAL, pp. 2-7. Some of Mr. McCuen's thinking about research is presented on the inside cover page of that issue.)

His work as an engineer has resulted in 16 patents, covering such areas as spring suspension, oil coolers, crankcase ventilation, radiator design, and manifolds. His technical papers have included topics on engine-fuel research and on analysis of the research and engineering opportunities existing for today's engineers.

Mr. McCuen is a member of the Society of Automotive Engineers, Engineering Society of Detroit, and the Industrial Research Institute, Incorporated.

ROBERT D. McLANDRESS,

contributor of "Methods Engineering for More Effective and Economical Use of Manpower," serves as director of the Work Standards and Methods Engineering Section of the Manufacturing Staff, Central Office, Detroit.

Directly after receiving the B.S. degree from Michigan State College in 1927, Mr. McLandress joined the Cadillac Motor Car Division as a clerk in the Accounting Department. In January 1928 he transferred to the Central Foundry Division as assistant employment manager and for the next ten years remained with this Division serving as safety engineer, supervisor of work standards and methods engineering, and production manager.

In August 1938 Mr. McLandress transferred from Central Foundry Division to become a member of the executive training staff at General Motors Institute for the next two years. From September 1940 to October 1942 he was employed by the Bendix Aviation Corporation.

Mr. McLandress joined Saginaw Steering Gear Division in October 1942 as supervisor of work standards and methods engineering and later became personnel director. He was transferred to his present position on the Manufacturing Staff, Central Office, in February 1947.

Mr. McLandress is the author of a number of papers among which are: "The Role of Industrial Engineering in Cost Reduction," "Machine Tools and Men," "Methods Engineering—A Procedure Which Eliminates the Wasteful Expenditure of Effort and Increases the Efficiency of Operations," and "Manpower Utilization." He is a member of the Engineering Society of Detroit and the Society for the Advancement of Management.

CHARLES E. MELDRUM,

contributor of "The Elimination of Safety Hazards in Press Operations," is assistant superintendent of the Elyria, Ohio plant of Brown-Lipe-Chapin Division. Mr. Meldrum has spent his entire General Motors career with this Division, starting at the main plant in Syracuse, New York, in September 1937 as a General Motors Institute student. His experience has been related entirely to press room operations. While a G.M.I. student, he filled such positions as press operator and die setter. He served for a three-year period in the army during World War II, and was engaged principally in small arms repair work.

Following his discharge from military service in the fall of 1945, he returned to Brown-Lipe-Chapin in Syracuse as a process engineer. The Division soon afterward was engaged in an expansion program. When the new plant in Elyria, Ohio, was completed in 1947, Mr. Meldrum was one of those selected to transfer to the new facilities. He was made foreman of the Press Room. Four years later, he was made general foreman of the Press Room, and in July 1952 he became assistant superintendent of the Elyria plant. He holds the degree of Bachelor of Industrial Engineering from General Motors Institute.

JOSEPH M. NEWMAN,

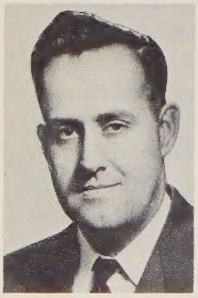
co-contributor of "An Engineering Solution for the Development of a Civilian-Military Factory," is plant engineer at the Kansas City Plant of the Buick-Oldsmobile-Pontiac Assembly Division. He completed 27 years as a General Motors engineer in August.

Mr. Newman received the bachelor of science degree in mechanical engineering in 1926 from Michigan State College just prior to joining General Motors. While with the Oldsmobile Division, he continued his studies and earned the professional mechanical engineering degree in 1936.

Mr. Newman joined the Plant Engineering Department of the Oldsmobile Division at Lansing, Michigan in 1926. Later he was made supervisor of plant engineering design. While serving in these capacities, Mr. Newman was active in the planning and equipping of 18 new buildings added to the Oldsmobile plant during the period from 1926 to 1939. In 1940 he became assistant plant engineer for Oldsmobile and was promoted to chief plant engineer in July 1943, in which capacity he served for the duration of World War II.

In 1943-44, Mr. Newman assisted in the reconversion of the Oldsmobile Forge Plant. Completed in record time, the project expanded the plant one-and-one-half times, an addition of 295,000 sq ft, and included the installation of heavy, complex equipment. Reconversion was almost completed when Mr. Newman was transferred, in October 1945, to his present position at Kansas City with the B.O.P. Division.

MARIO A. PARRAN,



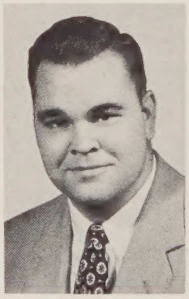
contributor of "Mathematics Necessary for Quality Control in Mass Production," is supervisor of quality control in the Inspection Department of Hyatt Bearings Division, Clark Township, New Jersey.

Mr. Parran has been with the Division since his initial employment in October 1934 as a toolmaker apprentice in the Apprentice School at Harrison, New Jersey. He was promoted to toolmaker in June 1938, to junior test engineer in December 1939, and to test engineer in June 1944. In November 1951 he was transferred to the Clark Township plant as general foreman in the Inspection Department and was promoted to his present position in December 1952. While employed at Hyatt Bearings, Mr. Parran earned his B.S. degree in mechanical engineering from the City College of New York in 1947.

At present, he is concerned with applying quality control methods to reduce scrap. Previously, Mr. Parran worked on improving bearing life and performance. This particular manuscript on quality control is an adaptation of his paper given before the Mathematics Institute for High School Teachers held during the University of Virginia's Summer Session, August 1953.

Mr. Parran is a senior member of the American Society for Quality Control.

GEORGE N. SHAMPO,



contributor of this issue's "Notes About Inventions and Inventors," has been associated with the Patent Section, Central Office Engineering Staff, Detroit, since July 1949.

His duties as patent attorney include the prosecution of patent applications on inventions originating with General Motors employes, the handling of patent infringement questions, and the negotiation of license agreements and other contracts. His present work is primarily in the chemical field and involves the handling of chemical, metallurgical, and foundry patent problems. He is particularly concerned with the patent problems of the Research Laboratories, Central Foundry, and Fabricast Divisions of General Motors.

Mr. Shampo is a chemical engineering graduate of the University of Wisconsin. During World War II he served in the Navy for two and one-half years, principally as a fighter direction and combat information center officer aboard a destroyer. After release from the Navy, Mr. Shampo returned to the University of Wisconsin Law School and subsequently received the L.L.B. degree from that institution. He also was elected to the Order of the Coif, national honorary legal society.

Mr. Shampo is a member of both the Wisconsin and Michigan bars.

LYLE A. WALSH,

contributor of "Facilities and Operations of the General Motors Engineering Staff," serves as manager of Engineering Staff Activities. Mr. Walsh's recent major project has been assisting with the planning and building of the Engineering Staff facilities at the new General Motors Technical Center being constructed on 818 acres north of Detroit. Mr. Walsh has been managing the Engineering Staff activities at the Technical Center since October 1950 when he transferred from the Central Offices in Detroit to the recently completed Engineering Building at the Technical Center.

University of Michigan granted Mr. Walsh the B.S. degree in mechanical engineering in 1926. In July of the same year, he was employed by the Oldsmobile Division in Lansing, as a student engineer. In 1927, he was transferred to the Experimental Department of this Division and served in various experimental and engineering capacities in the Oldsmobile and Buick Motor Divisions for the next ten years.

In February 1937, he was transferred to the GM Central Office as assistant to O. E. Hunt, vice president in charge of engineering. Since that time, he has served under Mr. Hunt's successors in office, Messrs. C. L. McCuen, J. M. Crawford, and, at present, C. A. Chayne.

Mr. Walsh's technical affiliations include membership in Tau Beta Pi, honorary engineering fraternity; the Society of Automotive Engineers; and the Engineering Society of Detroit.

Contributors' backgrounds vary greatly in detail but each has achieved a technical responsibility in the field in which he writes.

Faith of the Engineer

I AM AN ENGINEER. In my profession I take deep pride, but without vainglory; to it I owe solemn obligations that I am eager to fulfill.

As an Engineer, I will participate in none but honest enterprise. To him that has engaged my services, as employer or client, I will give the utmost of performance and fidelity.

When needed, my skill and knowledge shall be given without reservation for the public good. From special capacity springs the obligation to use it well in the service of humanity; and I accept the challenge that this implies.

Jealous of the high repute of my calling, I will strive to protect the interests and the good name of any engineer that I know to be deserving; but I will not shrink, should duty dictate, from disclosing the truth regarding anyone that, by unscrupulous act, has shown himself unworthy of the profession.

Since the Age of Stone, human progress has been conditioned by the genius of my professional forebears. By them have been rendered usable to mankind Nature's vast resources of material and energy. By them have been vitalized and turned to practical account the principles of science and the revelations of technology. Except for this heritage of accumulated experience, my efforts would be feeble. I dedicate myself to the dissemination of engineering knowledge, and especially to the instruction of younger members of my profession in all its arts and traditions.

To my fellows I pledge, in the same full measure I ask of them, integrity and fair dealing, tolerance and respect, and devotion to the standards and the dignity of our profession; with the consciousness, always, that our special expertness carries with it the obligation to serve humanity with complete sincerity.

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